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THE PRINCIPLES
OF
ORGANIC CHEMISTRY

BY

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PREFACE

This book is the outcome of a number of years' experience in teaching the elements of organic chemistry to classes of beginners in the subject. In it an attempt has been made to emphasize the fundamental principles of the science, and to describe in some detail the organic compounds of practical importance. The substances considered have been selected from this point of view. As a consequence, many compounds of interest to the more advanced student have been omitted; the space gained in this way has been devoted to a fuller consideration of the more important typical reactions of organic compounds, and the applications of the science have been treated at greater length than is customary in elementary text-books.

The order in which the several classes of compounds are discussed differs from that usually followed, and is the result of the emphasis placed on the effect of the nature of organic radicals on the properties of compounds containing them. To bring out clearly this effect, the radicals are referred to hydrogen as a standard; those more base-forming than hydrogen are classed as positive, and those more acid-forming as negative. The selection of the terms positive and negative is, perhaps, unfortunate, on account of the fact that these words have been used in other connections with a different meaning from that employed here. But no more expressive terms appear to be available, and they have been often used in organic chemistry with the significance assigned to them in this book. Alcohols consist of a positive radical in combination with the hydroxyl group, and acids of a negative radical with this group. This view leads to a consideration of acids after alcohols have been described. The relationship existing between the two classes of compounds and their analogies to inorganic bases and acids, can be clearly emphasized from this point of view. Next are considered ethers, anhydrides, and esters, compounds which contain respectively, two positive radicals, two negative radicals, and one positive and one negative radical linked to oxygen. The classing of these three types of compounds together makes it possible to bring out the relationship between the properties of compounds and the character of the radicals they contain. The consideration of alkyl and acyl halides, and of amines and amides in a similar way facilitates markedly the study of the properties of these compounds.

On account of the increasing attention paid to organic chemistry as a basis for the study of foods, the carbohydrates, fats, and proteins have been treated more fully than is customary in elementary text-books. Although the investigations of Fischer and his co-workers have placed the study of the proteins on a scientific basis, work has not advanced sufficiently far to warrant a strictly chemical classification of these compounds. The proteins are considered, therefore, according to the classification adopted by the American Society of Biological Chemists and the American Physiological Society. Some of the more important results of Fischer in the study of the hydrolysis of proteins and the syntheses of polypeptids have been given.

The methods used in the identification of organic substances have been described and illustrated by examples. The reactions of analytical significance of the various classes of compounds have been summarized in Chapter XVII. The identification of simple substances is becoming more and more a part of the laboratory practise in organic chemistry. The experience of the author has convinced him that this kind of work has great pedagogical value and can replace profitably a part of the synthetic work of the student. The book aims to furnish the elementary facts required for such work. In Chapter XVII the methods of deducing the structure of a compound from the results of the ultimate analysis of the compound and certain of its derivatives are illustrated by examples.

Problems are given at the end of most of the chapters. These are not merely "quiz" questions on the text; their solution involves, in most cases, a careful study of the principles discussed and their intelligent application. The solution of problems such as those given has been found to be of the greatest value to the student.

The author wishes to express his thanks to Prof. W. T. Hall, of the Massachusetts Institute of Technology and Prof. Alice F. Blood, of Simmons College, for valuable criticism and suggestions. He is especially grateful to his wife, who copied the entire manuscript of the book, assisted in proof-reading, and helped in many ways that made the preparation of the book possible.

J. F. NORRIS.

CONTENTS

PAGE

CHAPTER I. — SCOPE AND METHODS OF ORGANIC CHEMISTRY . . . 1

Importance and applications of organic chemistry, 3 — Sources of organic compounds, 4 — Determination of melting-points, 5 — Determination of boiling-points, 6 — Crystallization, 7 — Fractional distillation, 8 — Qualitative analysis, 10 — Quantitative analysis, 11 — Determination of empirical formulas, 13 — Determination of molecular weights, 14 — Structure of organic compounds; Isomerism, 18.

CHAPTER II. — HYDROCARBONS OF THE METHANE SERIES 22

Classification of hydrocarbons, 22 — Methane, 23 — Preparation of methane, 24 — Chemical properties of methane, 27 — Structure of methane, 30 — Ethane, 30 — Propane, 2 — Butanes, 33 — Pentanes, 34 — Higher members of the methane series, 36 — Heat of combustion and heat of formation, 38 — Chemical properties of the paraffins, 39 — Detection of the paraffins, 40 — Petroleum, 40.

CHAPTER III. — HYDROCARBONS OF THE ETHYLENE SERIES . . . 43

Ethylene, 43 — Structure of ethylene, 46 — Propylene, 49 — Butylenes, 50 — Higher members of the ethylene series, 51 — Identification of the hydrocarbons of the ethylene series, 52 — Heat of combustion and heat of formation of the hydrocarbons of the ethylene series, 53.

CHAPTER IV. — HYDROCARBONS OF THE ACETYLENE SERIES: DIOLEFINES 55

Acetylene, 56 — Structure of acetylene, 59 — Higher members of the acetylene series, 60 — Identification of compounds containing a triple bond, 60 — Diolefines, 61 — Isoprene, 61.

CHAPTER V. — MONATOMIC SATURATED ALCOHOLS . . . 63

Methyl alcohol, 63 — Chemical properties of methyl alcohol, 65 — Structure of methyl alcohol, 70 — Ethyl alcohol, 70 — Absolute alcohol, 72 — Alcoholic beverages, 72 — Analysis of alcoholic beverages, 73 — Uses of ethyl alcohol, 74 — Chemical properties of ethyl alcohol, 74 — Principles of oxidation applied to alcohol, 77 — Propyl alcohols, 79 — Butyl alcohols, 82 — Tertiary alcohols, 82 — Amyl alcohols, 83 — Optical activity: stereo-chemistry, 83 —

PAGE

Nomenclature of alcohols, 86 — Properties of the monatomic saturated alcohols, 87 — General methods of preparing alcohols, 88 — Reactions of alcohols of analytical significance, 91.

CHAPTER VI. — UNSATURATED ALCOHOLS. POLYATOMIC ALCOHOLS . 94
Vinyl alcohol, 94 — Allyl alcohol, 94 — Propargyl alcohol, 95 — Polyatomic alcohols, 96 — Glycol, 96 — Glycerol, 97 — Higher polyatomic alcohols, 102.

CHAPTER VII. — MONOBASIC ACIDS 103
Formic acid, 105 — Acetic acid, 107 — Vinegar, 107 — Preparation of acetic acid, 108 — Uses of acetic acid, 109 — Synthesis of acetic acid, 110 — Reactions of acetic acid, 111 — Structure of acetic acid, 112 — Tests for acetic acid, 113 — Higher fatty acids, 114 — Nomenclature of the fatty acids, 116 — Propionic acid, 116 — Butyric acid, 117 — Valeric acid, 117 — Palmitic acid, 118 — Soaps, 118 — Properties of acids of analytical significance, 120 — Unsaturated monobasic acids, 121 — Acrylic acid, 121 — Crotonic acids, 124 — Oleic acid, 126 — Acids with two double bonds, 128 — Sorbic acid, 128 — Linoleic acid, 128 — Acids with one triple bond, 129 — Propiolic acid, 129.

CHAPTER VIII. — POLYBASIC ACIDS 131
Oxalic acid, 132 — Malonic acid, 136 — Succinic acid, 137 — Isosuccinic acid, 138 — Fumaric and maleic acids, 138 — Aconitic acid, 140.

CHAPTER IX. — ETHERS, ANHYDRIDES, AND ESTERS 142
Ethyl ether, 143 — Properties of ethers of analytical significance, 147 — Acetic anhydride, 148 — Succinic anhydride, 150 — Properties of anhydrides of analytical significance, 151 — Esters, 151 — Esters of inorganic acids, 152 — Ethyl nitrate, 153 — Ethyl nitrite, 153 — Isoamyl nitrite, 154 — Methyl sulphate, 154 — Ethyl hydrogen sulphate, 154 — Ethyl acetate, 155 — Ethyl malonate, 160 — Malonic ester synthesis, 161 — Esters of polyatomic alcohols; fats, 163 — Waxes, 166 — Properties of esters of analytical significance, 166.

CHAPTER X. — ALDEHYDES AND KETONES . . . 169
Nomenclature of aldehydes and ketones, 171 — Formaldehyde, 172 — Tests for formaldehyde, 174 — Acetaldehyde, 175 — Polymerization of aldehyde, 180 — Structure of aldehyde, 183 — Homologues of aldehyde, 183 — Properties of aldehydes of analytical significance, 183 — Acrylic aldehyde, 184 — Geranial, 185 — Acetone, 186 — Homologues of acetone, 188 — Reactions of ketones of analytical significance, 190.

PAGE

CHAPTER XI. — Amines and Amides 191

Methylamine, 193 — Dimethylamine, 197 — Trimethylamine, 199 — Tetramethyl-ammonium hydroxide, 199 — Homologues of the methylamines, 200 — Reactions of amines, 201 — Identification of amines, 201 — Vinylamine 203 — Neurine, 203 — Choline, 204 — Lecithins, 204 — Muscarine, 205 — Ethylene diamine, 205 — Amides, 206 — Acetamide, 206 — Structure of amides, 208 — Urea, 209 — Guanidine, 211 — Carbamic acid, 211 — Oxamide, 212 — Succinamide, 213 — Identification of amides, 214.

CHAPTER XII. — Cyanogen and Related Compounds . . . 216

Cyanogen, 216 — Cyanogen chloride, 217 — Cyanamide, 218 — Hydrocyanic acid, 219 — Potassium cyanide, 220 — Potassium ferrocyanide, 222 — Potassium ferricyanide, 222 — Methyl cyanide, 224 — Methyl isocyanide, 226 — Cyanic acid, 228 — Potassium cyanate, 229 — Cyanuric acid, 229 — Fulminic acid, 229.

CHAPTER XIII. — Halogen Compounds . . 230

Alkyl halides, 230 — Preparation of alkyl halides, 232 — Reactions of alkyl halides, 234 — Identification of alkyl halides, 235 — Unsaturated halogen compounds, 236 — Vinyl bromide, 237 — 1-Brompropylene, 237 — 2-Brompropylene, 237 — 3-Brompropylene, 238 — Methylene chloride, 239 — Methylene iodide, 239 — Chloroform, 240 — Iodoform, 242 — Carbon tetrachloride, 242 — Ethylene bromide, 243 — Trimethylene bromide, 244 — Physical properties of acyl halides, 245 — Preparation of acyl halides, 246 — Reactions of acyl halides, 247 — Carbonyl chloride, 248 — Succinyl chloride, 249 — Identification of acyl chlorides, 249 — Compounds containing a halogen joined to nitrogen, 250 — Methyldichloramine, 250 — Acetbromamide, 250 — Acetdibromamide, 251.

CHAPTER XIV. — Compounds Containing Two Unlike Substituents 253

Halogen substitution-products of the acids, 254 — Reactions of the halogen derivatives of the fatty acids, 256 — Chloracetic acid, 258 — Dichloracetic acid, 258 — Trichloracetic acid, 258 — α-Brompropionic acid, 258 — β-Iodopropionic acid, 259 — α, β-Dibrompropionic acid, 259 — Monobasic hydraxyacids, 259 — Glycollic acid, 262 — Lactic acid, 262 — Hydracrylic acid, 265 — Glyceric acid, 266 — Tartronic acid, 267 — Malic acid, 267 — Dihydroxysuccinic acids, 269 — *d*-Tartaric acid, 271 — Tests for tartaric acid, 273 — Racemic acid, 274 — *l*-Tartaric acid, 275 — Mesotartaric acid, 275 — Citric acid, 275 — Saccharic acid and mucic acid, 277 — Glyoxylic acid, 278 — Pyroracemic acid, 279 — Acetoacetic acid, 280 — Acetoacetic ester synthesis: tautomerism, 280 — Halogen derivatives of alcohols, 286 — Halogen

PAGE

derivatives of aldehydes, 287 — Halogen derivatives of ketones, 289 — Preparation of amino-acids, 291 — Reactions of amino-acids, 291 — Glycine, 292 — Creatine, 293 — Alanine, 293 — Leucine, 293 — Ornithine, 294 — α-Asparagine, 294 — The nature of radicals and the effect of structure on the activity of acids, 294.

CHAPTER XV. — CARBOHYDRATES 299

Dextrose, 300 — Specific rotation of optically active substances, 301 — Preparation of dextrose, 302 — Structure of dextrose, 303 — Chemical properties of dextrose, 304 — Enzymes, 306 — Glucosides, 306 — *d*-Fructose, 308 — Structure of *d*-fructose, 308 — Chemical properties of *d*-fructose, 309 — *i*-Fructose, 310 — *d*-Galactose, 310 — Synthesis of monoses, 311 — Trioses, tetroses, pentoses, 312 — Erythrose, 313 — Arabinose and xylose, 313 — Disaccharides, 314 — Sucrose, 314 — Chemical properties of sucrose, 315 — Quantitative determination of sucrose, 318 — Lactose, 318 — Maltose, 319 — Raffinose, 319 — Polysaccharides, 320 — Starch, 321 — Dextrin, 322 — Glycogen, 323 — Inulin, 323 — Cellulose, 323 — Gums, 327 — Identification of carbohydrates, 327.

CHAPTER XVI. — COMPOUNDS CONTAINING PHOSPHORUS, ARSENIC, SULPHUR, METALS 329

Mercaptans, 331 — Sulphides, 332 — Sulphonal, 332 — Thioacids, 333 — Thioaldehydes and thioketones, 333 — Sulphonic acids, 334 — Taurine, 334 — Sulphoacetic acid, 335 — Thiocyanic acid, 335 — Alkyl thiocarbonates, 336 — Organo-metallic compounds, 337 — Zinc ethyl, 337 — Magnesium compounds, 338.

CHAPTER XVII. — THE IDENTIFICATION OF ORGANIC COMPOUNDS AND THE DETERMINATION OF THEIR STRUCTURE 340

Identification of unknown substances, 346 — Separation of mixtures, 349 — Determination of structure, 350.

CHAPTER XVIII. — URIC ACID AND RELATED COMPOUNDS . . 355

Uric acid, 355 — Parabanic acid, 356 — Alloxan, 356 — Allantoine, 357 — Structure of uric acid, 357 — Purine, 358 — Xanthine, 358 — Theobromine, 359 — Caffeine and theine, 359.

CHAPTER XIX. — CYCLIC HYDROCARBONS 360

Structure of benzene, 360 — Sources of aromatic compounds, 364 — Classes of aromatic compounds, 365 — Hydroaromatic compounds, 366 — Preparation of aromatic hydrocarbons, 368 — Characteristic reactions of aromatic compounds, 372 — Benzene, 373 — Toluene, 375 — Xylenes, 376 — Cymene, 376 — Mesitylene, 376 — Diphenylmethane, 377 — Triphenylmethane, 378 — Diphenylethane, 378 — Tetraphenylethane, 378 — Hexaphenylethane, 379 — Sty-

PAGE

rene, 380 — Stilbene, 381 — Tetraphenylethylene, 381 — Phenylacetylene, 381 — Tolane, 382 — Diphenyl, 382 — Naphthalene, 383 — Anthracene, 385 — Hexamethylene, 388 — Menthane, 388 — Cyclohexene, 388 — Cyclohexadiene, 389.

CHAPTER XX. — DETERMINATION OF THE STRUCTURE OF AROMATIC COMPOUNDS. NITRO COMPOUNDS AND SULPHONIC ACIDS . . 391

Influence of the nature of the radicals present in a compound on the position taken by substituents, 394 — Nitro compounds, 396 — Nitrobenzene, 397 — Dinitrobenzenes, 397 — Nitrotoluenes, 398 — Nitrostyrene, 399 — *o*-Nitrophenylacetylene, 399 — Nitronaphthalenes, 399 — Identification of nitro compounds, 399 — Sulphonic acids, 400 — Benzenesulphonic acid, 402 — Benzenesulphonyl chloride, 403 — Benzenesulphonamide, 403 — Toluenesulphonic acids, 404 — Naphthalenesulphonic acids, 404 — Identification of sulphonic acids, 404.

CHAPTER XXI. — HALOGEN DERIVATIVES OF AROMATIC HYDROCARBONS 406

Reactions of aromatic halogen compounds, 409 — Identification of aromatic halogen compounds, 410 — Brombenzene, 411 — Dibrombenzenes, 411 — Iodobenzene, 412 — Chlortoluenes, 412 — Benzyl chloride, 413 — Benzophenone chloride, 413 — Triphenylchlormethane, 414.

CHAPTER XXII. — AROMATIC AMINES AND OTHER REDUCTION PRODUCTS OF NITRO COMPOUNDS 416

Primary amines, 417 — Secondary amines, 419 — Tertiary amines, 419 — Diamines, 420 — Aniline, 420 — Acetanilide, 422 — Toluidines, 422 — Benzylamine, 424 — Naphthylamines, 424 — Methylaniline, 425 — Diphenylamine, 425 — Dimethylaniline, 426 — Identification of aromatic amines, 426 — Intermediate reduction-products of nitrobenzene, 427 — Azoxybenzene, 429 — Azobenzene, 429 — Hydrazobenzene, 429.

CHAPTER XXIII. — DIAZO COMPOUNDS 431

Reactions of diazonium salts, 432 — Diazonium compounds, 434 — Aminoazo compounds, 435 — Hydroxyazo compounds, 436 — Hydrazines, 436 — Structure of diazo compounds, 437 — Aliphatic diazo compounds, 440.

CHAPTER XXIV. — AROMATIC ALCOHOLS, PHENOLS, AND ETHERS . 442

Benzyl alcohol, 442 — Diphenylcarbinol, 444 — Triphenylcarbinol, 444 — Cinnamyl alcohol, 445 — Chemical properties of phenols, 446 — Phenol, 448 — Cresols, 448 — Carvacrol and thymol, 448 — Naphthols, 449 — Pyrocatechol, 449 — Resorcinol, 450 — Quinol,

PAGE

450 — Pyrogallol, 451 — Phloroglucinol, 451 — Hexahydroxybenzene, 452 — Identification of phenols, 453 — Ethers, 453 — Anisol, 453 — Phenetol, 454.

CHAPTER XXV. — AROMATIC ACIDS 456

Preparation of aromatic acids, 456 — Chemical properties of aromatic acids, 458 — Benzoic acid, 458 — Benzoyl chloride, 459 — Benzoic anhydride, 459 — Benzamide, 460 — Benzonitrile, 460 — Toluic acids, 460 — Phenylacetic acid, 461 — Cinnamic acid, 461 — Phenylpropiolic acid, 463 — Phthalic acid, 463 — Phthalyl chloride, 464 — Phthalic anhydride, 464 — Phthalimide, 465 — Isophthalic acid, 465 — Terephthalic acid, 466 — Mellitic acid, 466.

CHAPTER XXVI. — AROMATIC ALDEHYDES, KETONES, AND QUINONES 468

Benzaldehyde, 469 — Benzaldoxime, 472 — Cuminic aldehyde, 472 — Cinnamic aldehyde, 472 — Acetophenone, 473 — Benzophenone 474 — Ketoximes, 475 — Benzalacetone, 476 — Benzil, 476 — Quinone, 477 — Naphthoquinones, 480 — Anthraquinone, 481.

CHAPTER XXVII. — AROMATIC COMPOUNDS CONTAINING TWO OR MORE UNLIKE GROUPS 483

Nitrobrombenzenes, 483 — Benzoin, 484 — Nitrophenols, 485 — Picric acid, 485 — Bromphenols, 487 — Phenolsulphonic acids, 487 — Aminophenols, 488 — Guaiacol, 489 — Eugenol, 489 — Safrol, 480 — Salicylic aldehyde, 491 — Vanillin, 492 — Sulphanilic acid, 492 — Nitranilines, 492 — Nitrobenzoic acids, 494 — Dinitrobenzoic acids, 495 — Sulphobenzoic acids, 496 — Aminobenzoic acids, 497 — Salicylic acid, 498 — *m*-Hydroxybenzoic acid, 499 — *p*-Hydroxybenzoic acid, 499 — Mandelic acid, 499 — Tyrosine, 500 — Protocatechuic acid, 501 — Gallic acid, 501 — Tannic acids, 502 — Gallotannic acid, 503 — Caffetannic acid, 504 — Ionization constants of aromatic acids, 505.

CHAPTER XXVIII. — DYES 509

Substantive dyes, 511 — Adjective dyes, mordants, 511 — Ingrain colors, 512 — Nitro dyes, 513 — Aniline yellow, 513 — Butter yellow, 514 — Methyl orange, 514 — Bismarck brown, 514 — Congo red, 514 — Alizarin, 515 — Triphenylmethane dyes, 516 — Pararosaniline, 518 — Rosaniline, 519 — Methyl violet B, 519 — Crystal violet, 519 — Rosaniline blue, 519 — Malachite green, 520 — Victoria green 3B, 520 — Rosolic acid, 520 — Phthaleins, 521 — Fluoran, 522 — Fluorescein, 523.

CHAPTER XXIX. — TERPENES AND CAMPHORS 524

Pinene, 524 — Limonene, 525 — Camphor, 526 — Borneol, 527.

PAGE

CHAPTER XXX. — HETEROCYCLIC COMPOUNDS 528

Thiophene, 529 — Furfuran, 531 — Furfuraldehyde, 531 — Pyromucic acid, 532 — Pyrrole, 532 — Pyridine, 532 — Homologues of pyridine, 534 — Quinoline, 534 — Isoquinoline, 535 — Indole, 536 — Skatole, 536 — Indigo, 536 — Alkaloids, 538 — Nicotine, 539 — Atropine, 539 — Cocaine, 540 — Quinine, 540 — Strychnine, 540 — Morphine, 540.

CHAPTER XXXI. — PROTEINS 541

Physical properties of proteins, 541 — Chemical properties of proteins, 543 — Classification of proteins, 545 — Hydrolysis of proteins, 547 — Qualitative reactions of proteins, 549 — Albumins, 552 — Globulins, 553 — Glutelins and prolamines, 554 — Albuminoids, 554 — Histones, 555 — Nucleoproteins, 555 — Phosphoproteins, 557 — Hemoglobins, 558 — Derived proteins, 559 — Structure of proteins: peptids, 560.

ORGANIC CHEMISTRY

CHAPTER I

SCOPE AND METHODS OF ORGANIC CHEMISTRY

1. About the middle of the seventeenth century the study of the substances which occur in nature had so far developed that chemists grouped them, in an endeavor to systematize their knowledge, according to what they called the "three kingdoms" of nature. Chemistry was thus divided into three branches: animal, vegetable, and mineral. It was only when it was discovered later that certain compounds are formed in the growth of both animals and plants, that the distinction between animal and vegetable chemistry disappeared, and all substances produced as the result of organized life-processes were designated by the term *organic*. It was believed that organic compounds were formed as the result of the so-called "vital force" in living things, and that they could not be produced by the chemist. In 1828, however, Wöhler discovered that ammonium cyanate, a so-called inorganic compound, could be transformed into urea, a typical organic substance, which results from the changes that certain foods undergo in the body. As the study of organic compounds advanced, it was found that many of them could be prepared in the laboratory from the elements of which they are composed. The sharp distinction between inorganic and organic compounds based on the vital force, accordingly, disappeared. The term organic chemistry has survived, however. In this division of the science of chemistry, not only the substances formed as a result of life-energy in plants and animals are studied, but also the compounds prepared from these substances, of which many thousands are known.

The element carbon is present in all these so-called organic compounds, and as a consequence, organic chemistry may be defined as the chemistry of the carbon compounds. The student is already familiar with the chemistry of carbon in the elementary condition, of carbon monoxide and dioxide, and of the carbonates. As these substances are constituents of the mineral world they are considered as a part of inorganic chemistry. All other carbon compounds are classified, for convenience, under organic chemistry.

2. Although the compounds of carbon follow in their transformations the same fundamental laws as do the compounds of other elements, nevertheless, it is advisable to study them in detail after a knowledge of inorganic chemistry has been gained. A number of reasons have led to this setting off of the compounds of carbon for separate treatment. The chemical properties of these compounds are different from those of the analogous compounds of other elements; for example, the chlorides of the metals react with silver nitrate in aqueous solution, and are decomposed by concentrated sulphuric acid, whereas the chloride of carbon is comparatively inert and is not readily affected by these reagents. Again, when oxygen and hydrogen in the form of the hydroxyl group are in combination with carbon, as in alcohol, $C_2H_5.OH$, the substance is not affected by dilute acids or alkalies, whereas this group in combination with other elements imparts to the resulting compound acidic or basic properties. These differences between organic and inorganic compounds, and many others of a similar nature, are due to the fact that most inorganic compounds are broken down into ions when brought into solution, and act readily with other ionized substances, whereas in the case of organic compounds, a small number only undergo such ionization. Organic chemistry involves to a large extent the study of reactions between molecules, whereas in inorganic chemistry ionic reactions are of prime importance.

Many compounds of carbon exist which are unlike any known compounds of other elements. This is due to the fact that the carbon atom has the power to unite with itself and form molecules of great complexity. Compounds have been studied which contain over 60 carbon atoms in the molecule. Where so many atoms are present there is, evidently, opportunity for a number of different arrangements of the atoms; for example, there are 86 compounds of the formula $C_{10}H_{12}O_3$. This is an added source of complexity, and methods of study must be devised and used which are not necessary in inorganic chemistry where such complexity does not exist.

IMPORTANCE AND APPLICATIONS OF ORGANIC CHEMISTRY

3. The field covered by organic chemistry is a wide one. The changes which take place in our bodies involve the transformation of organic substances; the digestion and assimilation of food are chemical processes in which complex carbon compounds take part. As a consequence, a correct understanding of physiology requires a knowledge of physiological chemistry, which is a branch of organic chemistry. The investigation of the composition of foods and the study of methods for their analysis must be preceded by a study of the principles of organic chemistry upon which such investigation is based. The science of medicine makes use of many organic compounds on account of their effect on the body. An important branch of organic chemistry involves the preparation of new substances and a study of their action as drugs.

We come in contact with many organic compounds in our daily life on account of their useful or esthetic value, and such compounds assume an important place in commerce. In addition to foods, may be mentioned condiments, paints, illuminating oils, dyes, etc. The study of such substances involves the determination of the properties of the individual compounds and the changes which they undergo under a variety of circumstances. These transformations give the chemist such a clear conception of the nature of the compounds that in many cases it has been found possible to synthesize (*i.e.* build up) a substance which occurs in nature, from other simple and readily obtainable substances. The synthesis of Turkey red, a highly prized dye found in madder root, is an interesting example. Some years ago thousands of acres of land were given up to the growing of madder, in order to produce this dye. The substance, which is a definite chemical compound, was extracted in pure condition, and carefully studied. As a result, a method was devised to build up the dye from anthracene, a comparatively cheap substance, which is found in the tar formed when coal is distilled in the preparation of coal-gas. As the result of this application of organic chemistry the synthetic dye replaced that produced by nature, and large tracts of land were restored to agriculture.

Many valuable substances which occur in nature have been produced in the laboratory in a similar way. But the chemist has not been content to build up only naturally occurring compounds. Many new substances having valuable properties have been prepared. Synthetic dyes have been made in great variety, and many useful medicinal agents furnished the physician. Thus, synthetic organic chemistry is an important factor in the economics of the world and has become a source of wealth.

In addition to the applications of organic chemistry from the utilitarian point of view, the study of the compounds of carbon has resulted in the building up of a well developed science, and has increased to a marked degree our knowledge of the transformations in matter.

SOURCES OF ORGANIC COMPOUNDS

4. Organic compounds are formed in nature in the growth of plants and animals. From this source we obtain starch, sugar, fats, the so-called vegetable acids, cellulose, proteins, alkaloids, etc. Many of these substances undergo decomposition as the result of certain natural processes, or can be broken down into simple compounds by methods used in the laboratory. Fermentation yields many important compounds; alcohol is formed by this process when a solution of sugar which contains yeast is allowed to stand for some time. Acetic acid, which gives the acid taste to vinegar, is formed as the result of the fermentation of the sugar in the fruit from which the vinegar is prepared.

A large number of compounds are produced by what is known as destructive distillation. This process consists in heating substances which can not be converted into vapor without undergoing change, to such a temperature that decomposition takes place. As this temperature is often a high one, the substance is usually protected from the air in order to prevent complete combustion. A familiar example of destructive distillation is the manufacture of coal-gas. Coal is a mixture of certain complicated compounds of carbon, hydrogen, nitrogen, and other elements. At a high temperature these compounds are decomposed, and if air is excluded a large number of substances are formed. Illuminating gas and coal tar, which is rich in organic compounds of the greatest interest and value, are among the products formed. The destructive distillation of wood and of bones also yields important substances. Petroleum contains a large number of compounds of carbon and hydrogen. The sources mentioned furnish substances from which many others can be prepared by the application of the methods used in organic chemistry.

METHODS USED IN THE STUDY OF ORGANIC COMPOUNDS

5. The first step in the study of a substance is to obtain it in a pure condition. The tests which are usually applied in investigating the purity of an organic compound are based on the determination of certain physical properties. When a substance melts or boils without decomposition, the temperatures at which these changes take place under the same external conditions are definite and constant in the case of a pure substance. As determinations of melting-points and boiling-points are easily made, these properties are the ones usually studied in investigating the purity of most organic compounds.

Determination of Melting-points. — Melting-points are determined by using an apparatus which consists of a round-bottomed flask of 250 cc. capacity and a small test-tube which fits loosely in the neck of the flask and extends to within about one-half inch of the bottom. The flask is supported on an iron stand by means of a clamp, and filled with concentrated sulphuric acid to about three-fourths of its capacity. Sulphuric acid is placed in the test-tube also, care being taken to have the surface of the acid slightly below the level of that in the flask. The thermometer is held in place by means of a stopper, from which a slit has been cut so that the graduations of the thermometer are visible. The substance to be melted is powdered and placed in a small glass tube which has an internal diameter of about one millimeter. The tube is attached to the thermometer by means of a rubber band cut from a piece of the tubing used for making gas connections in the laboratory.

What is called the melting-point of a particular sample of any substance is the temperature at which the sample begins to melt and the temperature at which it completely liquifies. For example, these points were found to be 115° and 118°, respectively, in the case of an impure sample of benzoic acid. In this case the sample was said to have the melting-point 115°-118°.

When a substance is pure it melts at a definite temperature, that is, it completely liquifies at the temperature at which it first shows signs of melting. Such a substance is said to melt sharply. If a substance melts within 0.5° in the apparatus which has been described, it may be considered pure for most purposes.

The temperature read on the thermometer is usually taken as the melting-point. If this is high, however, a correction is made to eliminate the error arising from the fact that a part of the mercury is not heated to the temperature of the melting substance. When a correction is made the fact is noted thus, 205° (corr.). The number of degrees which must be added to the observed temperature is found from the formula $N(t - t')\ 0.000154$, in which N is the number of degrees of mercury outside the bath, t the observed temperature, and t' the average temperature of the stem outside the bath. The number 0.000154 is the coefficient of expansion of mercury in glass.

The melting-point of a substance is a valuable criterion of its purity and is much used in the study of organic compounds. The effect of an impurity in a substance on its melting-point is to cause the substance to melt over a certain range of temperature below the point where it melts sharply when pure. For example, an impure sample of benzoic acid melted at 116°-119°, whereas the pure substance melts at 121.4°. An impurity usually lowers the melting-point even if the impurity melts at a higher temperature than the substance itself. Thus, if triphenylmethane, which melts at 92°, is mixed with about one-fourth its weight of benzoic acid, which melts at 121.4°, the melting-point of the mixture becomes 79°-83°. The student is no doubt familiar with this principle in other cases, such as the influence of dissolved substances on the freezing-point of water.

6. Determination of Boiling-points. — In the case of liquids the boiling-point serves as a criterion of purity. The liquid is heated to boiling in a flask connected with a condenser, and the temperature noted as soon as the vapor begins to condense freely. The temperature is observed from time to time until only a small quantity of liquid remains in the flask. In the case of a pure substance the temperature remains constant during the distillation.

If the substance contains two or more compounds which are volatile, the temperature will rise as distillation proceeds. The temperature at which the vapor begins to condense and that observed when the distillation is stopped, are taken as the boiling-point of that portion of the liquid which has been distilled. It is necessary to note the two temperatures indicated, as taken together they serve as a valuable criterion of purity. Thus, a sample of benzene which boils at 80°-84° contains an appreciable amount of other substances. In determining the purity of a liquid it is distilled, and if the boiling-point is found to be constant it may, in general, be assumed to consist of but a single compound, and be, therefore, pure.[1]

As changes in the pressure of the atmosphere affect the boiling-points of liquids, both the temperature and pressure are frequently recorded, thus, 220° (750 mm.). When no pressure is specified, the normal pressure, 760 mm., is understood. When the boiling-point is taken at a pressure not far from this, a close approximation of the boiling-point at 760 mm. may be obtained by applying a correction of 0.1° for each 2.7 mm. of pressure. If the observed pressure is less than 760 mm. the correction should be added, and if greater it should be subtracted. A correction for stem-exposure should be made in the way described under the determination of melting-points.

PURIFICATION OF ORGANIC COMPOUNDS

7. Crystallization. — A substance which crystallizes and melts without decomposition can be purified in the following manner: The substance is melted and then allowed to cool slowly. When a large part has solidified the crystals are separated from the liquid by draining or washing with a solvent. This process may be repeated until a pure compound results. Benzene and acetic acid are frequently purified in this way. The method is based upon the fact that when a solution freezes, usually a part of the solvent first separates in the pure condition, leaving a more concentrated solution of the impurity, which, as a consequence, has a lower freezing-point. The separation of pure water in the form of ice from a solution of salt in water is a familiar example.

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[1] A number of mixtures which have constant boiling-points are known. The student is familiar with such a mixture of hydrochloric acid and water, and will recall the fact that the composition of the mixture may be varied by changing the pressure under which the distillation is effected. Mixtures of organic compounds are known which behave in a similar manner.

Although the process just described is efficient, it is wasteful, and crystallization from a solvent is usually used. The substance to be purified is dissolved in a liquid from which it will separate as crystals, either on spontaneous evaporation or when the warm saturated solution cools. Separation of a pure compound from a mixture usually can be effected in this way, as the solubilities of the constituents of the mixture in the solvent will be different, and the least soluble substance will separate first. The melting-point of the crystals which separate is determined. If this point is not sharp the substance is recrystallized, and the melting-point redetermined. The process is repeated as long as recrystallization brings about a rise in melting-point. The substance is considered pure when recrystallization does not affect the melting-point. In order to obtain a substance in the pure condition quickly, it is well to select for the solvent, if possible, a liquid in which the impurity present is much more readily soluble than the substance to be purified.

8. Fractional Distillation. — When a mixture of two liquids which boil at different temperatures is distilled, the temperature of the vapor during the distillation rises, in most cases, from the boiling-point of one of the liquids to that of the other. The distillate which is collected at first, contains a large proportion of the lower boiling liquid, while that collected toward the end of the operation is rich in the higher boiling liquid. In order to separate the two, the mixture is subjected to what is called fractional distillation.

The process is carried out in the following way: The mixture is distilled slowly, and the receiver in which the distillate is collected is changed from time to time, as the boiling-point of the liquid rises. In this way the mixture is separated into what are called fractions. The number of fractions collected and the limits of the boiling-point of the various fractions, are determined by the difficulty of separating the mixture and the purity of the products desired. The lowest boiling fraction is next placed in a clean flask and distilled. When the temperature reaches that of the upper limit of the fraction, the heating is stopped, and the second fraction added to the flask. Distillation is then continued until the upper limit of this fraction is reached, the distillate being collected in the appropriate receiver. The process is continued in this way until all the fractions have been distilled a second time. It will be found as a result of this fractionation that the distribution of the liquid in the several fractions is different from that obtained the first time. The fractions which boil at temperatures near those of the boiling-points of the constituents of the mixture increase in volume. By repeating the process a sufficient number of times, practically all the liquid can be separated into its constituents.

In the following table are given the results of the fractional distillation of a mixture of 50 cc. of methyl alcohol and 50 cc. of water. The volumes of the fractions obtained after each of six fractionations are recorded.

	66°–68°	68°–78°	78°–88°	88°–98°	98°–100°
I	0.	1.5	47.	17.	31.
II	0.	33.5	14.	7.5	38.5
III	1.5	38.5	6.5	5.5	40.5
IV	15.	24.5	5.	3.	43.5
V	25.	16.	2.5	1.	44.5
VI	32.	7.5	1.	0.	45.5

When two liquids form a constant-boiling mixture, they can not be separated in pure condition by fractional distillation. The boiling-point of a mixture of ethyl alcohol and water, which contains 96 per cent by weight of the former, is lower than that of pure alcohol. As a consequence, when a mixture of the two substances is subjected to repeated fractional distillation, the constant-boiling mixture is obtained. In order to prepare pure alcohol it is necessary to remove the water from the mixture by chemical means. Very few cases of this kind are met with in the purification of organic compounds.

Many substances which decompose when heated to their boiling-points under atmospheric pressure distil unchanged when the pressure is reduced. The purification of such substances is conveniently effected by distilling them under diminished pressure. In order to do this the vessel in which the distillate is collected is connected with a pump which removes the air from the apparatus.

Substances which have an appreciable vapor pressure at 100°

can be separated from those which do not by passing steam through the mixture, and condensing the water-vapor which carries along with it the vapor of the volatile substance.

METHODS OF ANALYSIS

9. Qualitative Analysis. — After a substance has been obtained in a pure condition, the next step in its study is the qualitative determination of the elements of which it is composed. This is, in general, a simple process compared with the analysis of inorganic substances, as most organic compounds contain but a few elements, which are easily recognized. Many compounds contain carbon and hydrogen alone; still more contain these elements together with oxygen. Nitrogen, sulphur, and the halogens are frequently present, and a few compounds contain phosphorus, arsenic, boron, silicon, and similar elements.

The presence of *hydrogen* and *carbon* in organic compounds can be shown by heating them with copper oxide. The oxide is reduced, and carbon dioxide and water are formed. The carbon dioxide may be detected in the usual way with lime-water. The water formed will condense in the cold part of the tube in which the decomposition is effected.

When the non-metals are joined to carbon they do not show the reactions with which the student is familiar, on account of the fact that the compounds containing them are, in most cases, not ionized. In detecting these elements it is necessary, therefore, to convert them into compounds in which their presence can be discovered by the usual tests. This can be done by heating the compound to be analyzed with sodium. When decomposition has been effected in this way the non-metallic elements unite with the sodium, and sodium chloride, phosphide, sulphide, etc., are formed. If nitrogen is present it is found as sodium cyanide. The presence of these substances is detected by the methods of inorganic qualitative analysis.

A convenient and delicate way of detecting halogen in an organic compound is to introduce into the flame of a Bunsen burner a little of the substance on the end of a copper wire which has been previously cleaned by heating until it imparts no color to the flame. A halide of copper is produced, which volatilizes with the production of a brilliant green color.

10. Quantitative Analysis. — The determination of the percentage composition of a pure compound is called *ultimate analysis.* The methods used in ultimate organic analysis are simple in principle, but their successful application requires close attention to many details. Only the outlines of the process will be given here.

Carbon and *hydrogen* are estimated by burning a known weight of the substance and weighing the carbon dioxide and water formed. The substance to be analyzed is heated in a tube of hard glass through which oxygen is passed. In order to ensure complete combustion the gases formed are passed over copper oxide which is kept at a dull red heat. The products of combustion are passed, first through a tube containing calcium chloride, which absorbs the water, and then through a tube containing a solution of potassium hydroxide, which absorbs the carbon dioxide. If nitrogen is present the products of combustion are passed over heated copper in order to reduce the oxides of nitrogen formed during the combustion. If the oxides of nitrogen were allowed to pass through the tubes used to collect the water and carbon dioxide, they would be absorbed, and the increase in weight in the tubes could not be used in calculating the amount of hydrogen and carbon in the compound analyzed. If a halogen is present in the substance burned, the gases are passed over heated silver-foil.

Nitrogen may be determined conveniently in two ways. The *Dumas method* commonly used consists in burning the substance with copper oxide in a stream of carbon dioxide. The gases produced are passed over hot copper to reduce the oxides of nitrogen formed, and, finally, the volume of the nitrogen is measured, after the carbon dioxide present has been absorbed by a solution of potassium hydroxide. This is called the *absolute method.*

The *Kjeldahl method* for the determination of nitrogen is the one generally used in the analysis of food-products and other complex mixtures. The substance to be analyzed is heated with concentrated sulphuric acid until it is completely oxidized. The nitrogen present is converted into ammonia, which unites with the excess of sulphuric acid to form ammonium sulphate. The amount of ammonia formed is determined by treating the mixture of the acid and ammonium salt with an excess of sodium hydroxide, and distilling. The aqueous distillate, which contains the ammonia, is collected in a solution of a known quantity of acid. The difference between this amount of acid and that which is present after the ammonia has been absorbed, is a measure of the ammonia formed, and consequently of the nitrogen in the compound analyzed. The oxidation of the substance by sulphuric acid is facilitated by adding potassium sulphate, mercury, or other substances.

Sulphur is usually determined by the method described by Carius. The substance is heated in a sealed tube with fuming nitric acid, and the sulphuric acid so formed is precipitated as barium sulphate. The method for the *halogens* is similar. In this case silver nitrate is present in the tube during oxidation, and the silver halide formed is determined.

As the methods for determining *oxygen* are not entirely satisfactory, the percentage of this element is usually estimated by subtracting the sum of the percentages of the other elements present from 100.

It is often necessary in the analysis of a mixture of compounds to determine the proportions in which the constituents of the mixture are present. Many natural products used as foods or drugs, or in the manufacture of paints, dyes, etc., are mixtures in which compounds of known composition are present in varying proportions. Thus, milk contains water, fat, inorganic salts, and organic nitrogen compounds. The quantitative determination of the constituents of such mixtures is called *proximate analysis*. Many methods have been applied in this branch of quantitative analysis. They are based on the physical and chemical properties of the compounds which constitute the mixtures. A few typical methods are described in the chapter in which fats and oils are discussed.

EMPIRICAL AND MOLECULAR FORMULAS

11. The student is familiar from the study of inorganic chemistry with the methods used in expressing the composition of a compound by means of a formula. The formula SiO_2 means that silicon dioxide contains silicon and oxygen in the proportion one atomic weight (28.3 grams) of the former to two atomic weights (32 grams) of the latter. Such a formula, in which only the weight relations of the constituents of a compound are expressed, is called an *empirical formula.* In the case of many inorganic compounds it is possible to apply the molecular hypothesis. When this can be done the formula expresses not only the weight relations, but the number of atoms of each element which constitute the molecule. Such a formula is called a *molecular formula.* Thus, the symbol H_2O signifies not only that water contains two parts of weight of hydrogen to sixteen parts of oxygen, but that in the gaseous condition its molecule consists of two atoms of hydrogen and one of oxygen.

Determination of Empirical Formulas. — The method of determining the empirical formula of an organic compound from the results of its analysis is illustrated by the following example: A substance was found to contain 37.42 per cent carbon, 12.70 per cent hydrogen, and 49.88 per cent oxygen. This means that 100 grams of the compound contain 37.42 grams of carbon, 12.70 grams of hydrogen, and 49.88 grams of oxygen. In this statement the weights of the elements are all expressed in the same unit, namely grams. In a chemical formula the unit of weight is different for each element. When carbon is considered, for example, the unit is expressed by the letter C, which represents an atomic weight of the element. As 100 grams of the compound under consideration contain 37.42 grams of carbon, and as each unit of carbon weighs 12 grams, there are $37.42 \div 12$, or 3.11 units of carbon present. In the same way we find there are $12.70 \div 1$, or 12.70 units of hydrogen, and $49.88 \div 16$, or 3.10 units of oxygen. The compound thus contains carbon, hydrogen, and oxygen in the proportion of 3.11 to 12.70 to 3.10, respectively, if the unit of measure in each case is the atomic weight of the element. These numbers are approximately in the ratio of 1 to 4 to 1, and the empirical formula of the compound is CH_4O.

It is evident that any error in the percentage composition as determined by analysis affects the numbers obtained by dividing the percentages by the atomic weights. As all quantitative analyses are only close approximations to truth, we have a right to reduce ratios obtained as above to the smallest whole numbers which express these ratios within the degree of accuracy of the methods of analysis employed.

It will be seen from the above that in calculating the empirical formula of a compound the percentage of each element is first divided by its atomic weight; the smallest whole numbers are selected which are in the same ratio as the numbers so found; and, finally, a formula is written in which the number of atoms of each element present is the number found by the above calculation in each case.

In order to determine whether the formula so deduced is correct within the limits of error of the analysis made, the theoretical percentage composition of a compound having this formula should be calculated. In the example given, a compound having the formula CH_4O contains 12 parts by weight of carbon, 4 of hydrogen, and 16 of oxygen. In 32 parts of the compound there are, accordingly, 12 parts of carbon. Twelve thirty-seconds, or 37.50 per cent of the compound, is carbon. The percentages of oxygen and hydrogen are 50.00 and 12.50, respectively. The numbers obtained by analysis agree with these well within the limits of error of the methods used, and the calculated formula is, consequently, in accord with the facts.

DETERMINATION OF MOLECULAR WEIGHTS

12. A quantitative analysis of a compound tells us only the proportion by weight in which the elements are present in the compound. When we interpret these figures, using the conception of atoms of definite weight, we arrive at a formula which expresses the proportion in which the atoms present are combined. In the case of the compound studied in the last section, the formula arrived at was CH_4O. We can not determine by analysis whether the correct formula is the one given or some multiple of this, such as $C_2H_8O_2$ or $C_3H_{12}O_3$, as the percentage composition of all such compounds is the same. It is evident, therefore, that we must study some property of the compound in question which will enable us to decide which multiple is the correct one. The property selected is the molecular weight. The molecular weights of substances having the formulas given above are different. If CH_4O is correct the molecule weighs 32; if there are two atoms of carbon, it weighs 64, etc. A number of methods have been devised to determine molecular weights. A few of the more important ones will be described briefly.

The *method of Dumas* is based on Avogadro's principle that equal volumes of gases contain the same number of molecules, when the gases are measured under the same conditions of temperature and pressure. How this principle is applied is evident from the following consideration: Suppose one liter of hydrogen and one liter of the vapor of a substance the molecular weight of which is sought, are weighed separately under the same conditions, and it is found that the vapor weighs 16 times as much as the hydrogen. All the molecules of the vapor weigh sixteen times as much as all the molecules of the hydrogen, and since there are the same number of each, it follows that each molecule of the vapor weighs sixteen times as much as each molecule of hydrogen. For reasons which are familiar to the student, the molecular weight of hydrogen is taken as 2, as it can be shown that the molecule contains at least two atoms. The molecular weight of the substance under discussion is, therefore, 32. The molecular weight, accordingly, is equal to the vapor density compared with hydrogen multiplied by two. In carrying out the method it is only necessary to weigh a known volume of the substance in the gaseous condition at a convenient temperature and pressure. By an application of the gas laws the volume is reduced to 0° and 760 mm. pressure, and the ratio between the weight found and the weight of an equal volume of hydrogen is calculated. Twice the density so determined is the molecular weight.

In the *method of Victor Meyer* the density is determined by finding the volume of the vapor produced from a known weight of substance. As this can be done more readily than the weight of a known volume of vapor can be determined, the method has largely replaced that of Dumas.

13. Determination of Molecular Weight from the Boiling-point and Freezing-point of Solutions. — In order to determine the molecular weight of a compound by either of the methods just described, it is necessary to vaporize the substance. The methods are not applicable, therefore, to the large number of substances which can not be boiled without decomposition. The molecular weight of such substances is determined by methods which are based on the effect of dissolved substances on the boiling-point or freezing-point of liquids. These methods are generally applicable, and are often used instead of the method of Victor Meyer, especially in the case of substances which boil at high temperatures.

The study of the effect of a dissolved substance on the boiling-point of a liquid has shown that the rise in the boiling-point of a solvent produced by dissolving in it a non-ionized substance, is proportional to the weight of the substance dissolved, and inversely proportional to the weight of the solvent and to the molecular weight of the dissolved substance. These facts are expressed by the formula

$$\Delta = C\frac{S}{S' \times M}$$

where Δ = rise in boiling-point
S = weight of substance
S' = weight of solvent
M = molecular weight of substance
C = a constant

The value of C can be found for a solvent by determining the rise in boiling-point produced by dissolving a definite weight of a substance of known molecular weight in a definite weight of the solvent. For example, it has been found that when 0.625 grams of a substance having a molecular weight of 123 are dissolved in 20 grams of benzene, the boiling-point of the latter is raised 0.660°. If we substitute these values in the formula we have,

$$0.660 = C\frac{0.625}{20 \times 123}$$

From this we find that C is 2600. This is the value found for C whenever the solvent used is benzene. It is called the constant for benzene. In a similar way constants for other solvents can be found.

The equation given above can be changed into the form

$$M = \frac{C \times S}{S' \times \Delta}$$

If the constant for the solvent is known, it is evident that an unknown molecular weight can be determined by observing the change in boiling-point of the solvent produced by dissolving in it a known weight of substance. For example, the rise in the boiling-point of benzene was 0.200° when 0.232 grams of a certain substance were dissolved in 18 grams of the solvent. The molecular weight can be found by substituting these values in the formula.

$$M = \frac{2600 \times 0.232}{18 \times 0.200} = 168$$

The determination of molecular weights by means of the depression of the freezing-point is based upon the same principle as that underlying the determination by means of the rise in boiling-point. The same laws hold. The constants, however, for the various solvents are not the same as those used in calculating molecular weights by the boiling-point method.

In the experiment quoted to illustrate the method of finding the constant for benzene, 0.625 grams of a substance with the molecular weight 123, when dissolved in 20 grams of benzene, caused a rise in the boiling-point of 0.660°. If the freezing-point of this solution is taken it will be found to be 1.346° lower than that of the solvent. From this we can calculate, as before, the constant for benzene when the depression of the freezing-point is used to determine molecular weights.

$$1.346 = C \frac{0.625}{20 \times 123}$$

From this equation we find that $C = 5300$. The equation for calculating molecular weights is the same as that given above; in this case, however, Δ signifies the depression of the freezing-point and C is the freezing-point constant for the solvent used.

The constants calculated as above bear a simple relation to what are called the molecular elevation of the boiling-point and the molecular depression of the freezing-point. These quantities are the elevation of the boiling-point and the depression of the freezing-point produced by dissolving 1 gram-molecular-weight of any substance in 100 grams of the solvent. If we take the equation

$$\Delta = C \frac{S}{S' \times M}$$

and make S = M and S′ = 100 we have,

$$\Delta = C\frac{M}{100\,M} = \frac{C}{100}$$

The values for these quantities for a few solvents are given in the following table.

Solvent	Molecular Depression of Freezing-point	Molecular Elevation of Boiling-point
Water	18.5	5.2
Benzene	51.2	27.3
Phenol	74.	30.4
Ethylene bromide	118.	64.3

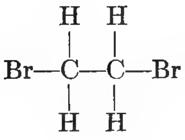
It is seen that the depression of the freezing-point is greater than the elevation of the boiling-point. On this account the determination of molecular weights by the freezing-point method is often preferred.

STRUCTURE OF ORGANIC COMPOUNDS. ISOMERISM

14. The methods used in the study of organic compounds which have been outlined up to this point, make it possible to write formulas for many substances which express their composition and molecular weight. It is the endeavor of chemists, however, to represent more than this by the formula of a compound. Thus, lead nitrate is written $Pb(NO_3)_2$ and not PbN_2O_6 in order to show clearly that the compound is related closely to nitric acid. In the case of most inorganic compounds little more is expressed by the formulas than percentage composition. Chemists have succeeded, however, in expressing in the formula of an organic compound many of the chemical properties possessed by the substance. This enlargement of the original meaning of a formula grew out of the necessity of distinguishing in some way between compounds which have the same percentage composition and molecular weight.

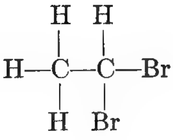
There are many organic compounds which have the same percentage composition; for example, 107 compounds having the formula $C_9H_{11}O_2N$ have been described. Such compounds are called *isomers* (signifying equal measure) and the phenomenon is known as *isomerism.* When such substances have the same molecular weight they are said to be *metameric,* but when the percentage composition is the same, and the molecular weights are different, they are classed as *polymers.* Benzene, C_6H_6, is a polymer of acetylene, C_2H_2. In this case the molecular formulas are different and there is no confusion, but in the case of metameric substances the formulas for all are the same. There are two substances, for example, which have the composition and molecular weight represented by the formula C_2H_6O. It is evident that the formula must be written in two ways if there is to be a distinct way of representing each compound. In this particular case one of the substances shows many of the properties of a hydroxide. This fact is emphasized by writing for it the formula $C_2H_5.OH$. The other compound is an oxide. This is shown by writing for it the formula $(CH_3)_2O$. Such formulas are sometimes called rational formulas.

It is evident that it is desirable to express as many facts as possible in the formula of a compound, and chemists have elaborated a valuable system of expressing the properties of substances in their study of organic compounds. This system has resulted from a special application of the theory of the atomic and molecular constitution of matter to organic compounds. In seeking an explanation of the phenomenon of isomerism, chemists came to the conclusion that if the molecules of two substances contain the same number and kinds of atoms in the same relative proportions, the difference between the two must be caused by a difference in arrangement of the atoms within each molecule. There are, for example, two compounds which have the formula $C_2H_4Br_2$. Two possible arrangements of the atoms in a molecule of this composition immediately suggest themselves. In one each carbon atom holds in combination with itself one bromine atom, and in the other both bromine atoms are joined to the same carbon atom. These arrangements could be represented thus:



$$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & \\ \mathrm{Br} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{Br} \\ & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

and



$$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{Br} \\ & & | & & | & & \\ & & \mathrm{H} & & \mathrm{Br} & & \end{array}$$

Formulas such as these, in which each combining power of the elements is represented by a line, are called *graphic formulas.* When a formula is written in a more condensed form, such as $BrCH_2.CH_2Br$ or $H_3C.CHBr_2$, which, however, expresses the facts indicated by the graphic representation, it is called a *structural* or *constitutional formula.*

A large part of the work in organic chemistry has had to do with the theory of arrangement of the atoms in molecules. Until recently this theory has not been made use of to any great extent in the study of inorganic compounds. On account of the greater simplicity of most of these compounds and the almost total lack of isomerism, it has not been necessary to consider the arrangement of the atoms in the molecule in order to account for the properties and reactions of compounds. The great advance in organic chemistry, however, and the success which has been attained in the building up of many important substances, have been the direct result of the extension of the atomic and molecular hypothesis to a consideration of the arrangement of the atoms in molecules.

Conclusions as to how the atoms are joined together in any compound are reached from an interpretation of the way in which the compound interacts with other substances. Many cases will be described in the following chapters. Some chemists take exception to the view that a study of the reactions of a substance gives information as to the actual structure of its molecules. They hold that a constitutional formula is nothing more than a short way of expressing the reactions of a substance. Such formulas are a kind of chemical shorthand. Other chemists believe that, as so many facts are in accord with the theory, and as the theory has stood so many tests, it is as well established as the theory of atoms and molecules itself. Whichever view is correct, we can say, at least, that organic compounds react *as if* their molecules were constituted as represented by their graphic formulas.

It is well for the student in the beginning to appreciate that structural organic chemistry is founded on a theory. But theory should not be neglected as the acquisition of the facts is much facilitated by learning them in the light of the theory. The study of any science must include a knowledge not only of the facts of the science, but of the current theories as well.

PROBLEMS

1. Calculate the percentage composition of (*a*) $C_{12}H_{22}O_{11}$; (*b*) C_2H_6S; (*c*) $C_6H_5NO_2$.

2. Calculate the empirical formulas of the substances which yielded the following results on analysis: (*a*) C, 52.10; H, 13.14; O, 34.76; (*b*) C, 79.00; H, 5.60; N, 15.48.

3. An analysis of a compound which contains C, H, and O gave the following results: weight substance 0.2727 gm., weight H_2O 0.3280 gm., weight CO_2 0.5990 gm. Calculate the formula of the compound.

4. A substance was found on analysis to contain 15.60 per cent H and 84.23 per cent C. In a determination of the vapor density of the compound it was found that the weight of 100 cc. of vapor reduced to 0° and 760 mm. was .063 gm. Calculate the molecular formula of the compound.

5. A compound of carbon and hydrogen gave the following results on analysis: 0.3420 gm. substance gave 1.0560 gm. CO_2 and 0.4860 gm. H_2O. In a determination of the vapor density by the method of V. Meyer it was found that 0.2010 gm. substance gave 42 cc. at 750 mm. and 15°. Calculate the molecular formula of the compound.

6. An analysis of a compound which contained nitrogen gave the following results: 0.6137 gm. substance gave 54 cc. N measured over water at 17° and 744 mm. (tension of water-vapor at 17° is 14 mm.). Calculate the percentage of nitrogen in the compound.

7. When 0.460 gm. of a substance was dissolved in 17 gm. benzene, the boiling-point of the solution was raised 0.391° Calculate the molecular weight of the compound.

8. When 0.620 gm. of a substance was dissolved in 15 gm. water, the freezing-point was lowered 0.102°. Calculate the molecular weight of the compound.

CHAPTER II

HYDROCARBONS OF THE METHANE SERIES

15. Classification of Hydrocarbons. — In a systematic study of the compounds of carbon it is advisable to begin with a consideration of the compounds which contain hydrogen and carbon only. These substances, which are called hydrocarbons, occur in nature, are formed in certain industrial processes, and have important uses. It is not for these reasons, however, that the hydrocarbons are first studied. They are, perhaps, the simplest organic compounds, and a knowledge of their properties and reactions is the best preparation for the study of more complex substances. Further, most compounds can be considered as derived from the hydrocarbons by the replacement of one or more hydrogen atoms by other atoms or groups of atoms.

A large number of hydrocarbons are known. Their study is greatly simplified by the fact that it is possible to classify them into a small number of groups. This classification of the hydrocarbons is based on their chemical properties, which are largely determined by the relation between the number of carbon and hydrogen atoms in the molecule. Thus, a great many hydrocarbons are very inert when brought into contact with other substances. They are not appreciably affected by concentrated sulphuric acid and nitric acid, and resist the action of strong alkalies and most oxidizing agents. Chlorine and bromine react with these hydrocarbons under certain conditions, and the hydrogen which they contain is replaced by halogen. Certain hydrocarbons which show these properties are called *paraffins* (from Latin *parum affinis*, small affinity) and are said to belong to the methane series, as methane, CH_4, is the simplest member of the group. Among the hydrocarbons in this series are ethane, C_2H_6, propane, C_3H_8, and octane, C_8H_{18}. It will be seen that the number of hydrogen atoms in each compound is two more than twice the number of carbon atoms. The general formula for the members of the series is C_nH_{2n+2}.

Other hydrocarbons are much more reactive than the paraffins; some unite directly with the halogens and with the halogen acids. Ethylene, C_2H_4, propylene, C_3H_6, and octylene, C_8H_{16}, belong to a series the members of which show these properties. These hydrocarbons each contain two less hydrogen atoms than the paraffin with the same number of carbon atoms. The general formula for this series is C_nH_{2n}.

One more example will be given. There are a number of important hydrocarbons which form characteristic compounds when they are treated with sulphuric acid or with nitric acid. Benzene, C_6H_6, toluene, C_7H_8, and xylene, C_8H_{10}, are examples. The general formula for these hydrocarbons is C_nH_{2n-6}.

16. Methane, CH_4, the first member of the paraffin series, is the only hydrocarbon which contains but one carbon atom. It is a colorless and odorless gas, slightly soluble in water, and has the specific gravity 0.559 compared with air. Its molecular weight is less than that of any other compound, and it is, consequently, the lightest compound gas known. Liquid methane boils at $-152°$ and solidifies at $-186°$.

Methane is produced as a result of the decomposition of many complex organic substances. It is formed when dead vegetable matter, such as leaves, grass, etc., undergoes disintegration under water in stagnant pools. For this reason it is called marsh gas. The gas which rises in bubbles when a mass of decaying leaves is stirred, is a mixture of methane, nitrogen, and carbon dioxide. Experiments in the laboratory indicate that the decomposition is brought about by the micro-organisms which breed in stagnant water. The chief constituent of leaves and other vegetable matter is a compound called cellulose. It has been shown that when filter-paper, which is pure cellulose, is subjected to the action of the bacteria in sewage, methane is one of the products of the decomposition which takes place.

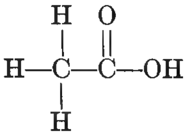
Other natural processes bring about the formation of this hydrocarbon. The intestinal gases which are formed as the result of the imperfect digestion of foods contain at times as much as 56 per cent of methane. The compound occurs in coal mines, and on account of the fact that it burns is called by miners fire-damp. Natural gas contains between 90 and 95 per cent methane. The method of the formation within the earth of large quantities of methane has aroused the interest of chemists. Some hold the view that the gas is formed as the result of the action of great heat on vegetable substances, while others are of the opinion that animal remains are the source of the gas. Recent study of the action of metals on carbon at high temperatures has furnished some evidence in favor of a third theory, according to which the gas is formed as the result of the action of water on certain metallic carbides. The fact that methane is formed when aluminium carbide reacts with water is evidence in favor of this theory. The equation for the reaction is,

$$Al_4C_3 + 12\,H_2O = 4\,Al(OH)_3 + 3\,CH_4$$

Illuminating gas contains methane. It is present to the extent of between 30 and 40 per cent in coal gas. Carbureted water gas contains 10-15 per cent methane. The hydrocarbon is produced during the process of enriching, which consists in heating water gas and naphtha vapor to a high temperature. Naphtha is a mixture of liquid hydrocarbons of the methane series. At the temperature to which it is heated the naphtha undergoes decomposition and gaseous compounds are formed. These consist largely of methane as this hydrocarbon resists to a high degree the action of heat. Most hydrocarbons when heated to the point of decomposition are converted largely into methane.

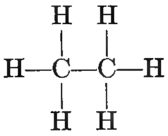
17. Preparation of Methane. — Methane can be prepared in a number of ways in the laboratory. Of theoretical interest is the fact that it is formed in small quantities when hydrogen is passed over an electric arc between carbon poles. It can be formed from carbon monoxide or carbon dioxide by passing a mixture of either of the gases and hydrogen over finely divided nickel at a temperature of about 250°. This metal, which acts as a catalytic agent, has been shown to be of particular value in bringing about the reduction of many organic compounds by means of free hydrogen.

A convenient laboratory method of preparing methane is to heat sodium acetate with soda lime, which is a mixture of sodium and calcium hydroxides. As organic acids or their salts are frequently used in the preparation of other compounds, it is well at this point to give a few facts about them. Acetic acid, which is described in detail in section **81**, is the acid contained in vinegar. It has the structure represented by the formula



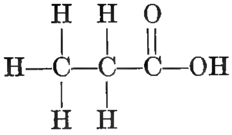
$$\begin{array}{ccccccc} & & H & & O & & \\ & & | & & \| & & \\ H & - & C & - & C & - & OH \\ & & | & & & & \\ & & H & & & & \end{array}$$

and may be considered as derived from methane by the replacement of a hydrogen atom by the group $-\overset{\overset{O}{\|}}{C}-OH$. This group is present in organic acids, and on account of its frequent occurrence has been given the name *carboxyl.* The acids, in general, may be considered as derived from hydrocarbons by the replacement of hydrogen by carboxyl. The acid derived from ethane



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

has the formula



$$\begin{array}{ccccccccc} & & H & & H & & O & & \\ & & | & & | & & \| & & \\ H & - & C & - & C & - & C & - & OH \\ & & | & & | & & & & \\ & & H & & H & & & & \end{array}$$

The structural formulas of these acids are usually written $CH_3.COOH$, $C_2H_5.COOH$, etc.

The preparation of methane from acetic acid can now be understood more readily. To obtain the hydrocarbon it is necessary to replace the carboxyl group by a hydrogen atom. This is accomplished by melting the salt of the acid with an alkali. The reaction may be represented thus: —

$$CH_3.\underline{|COONa + NaO|}H = CH_4 + Na_2CO_3$$

The reaction is of importance, not only because it furnishes a convenient way of preparing methane, but because it is an illustration of a general method used in the synthesis of organic compounds. When the salt of an acid is heated with an alkali, the carboxyl group is replaced by hydrogen. We can in this way convert any acid into the corresponding hydrocarbon.

The methane prepared in this way is contaminated with small quantities of other substances, which are formed as the result of the action of heat on sodium acetate alone. When a very pure sample of the hydrocarbon is desired, it is prepared by treating an alcoholic solution of methyl iodide, CH_3I, with a zinc-copper couple. In order to make clear this statement and others which are made later, the following facts are given at this point.

Methyl iodide is made by heating a concentrated aqueous solution of hydriodic acid with methyl alcohol (commonly called wood alcohol, because it is manufactured by heating wood to a high temperature): —

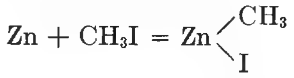
$$CH_3OH + HI = CH_3I + H_2O$$

The relation between methane, CH_4, methyl alcohol, CH_3OH, and methyl iodide, CH_3I, is shown by other hydrocarbons and their analogous derivatives. The hydroxyl derivatives are called alcohols. Thus we have ethane, C_2H_6, ethyl alcohol, C_2H_5OH, and ethyl iodide, C_2H_5I. The group of carbon and hydrogen atoms, CH_3, C_2H_5, etc., which is present in such a series of compounds, is called a *radical.* The names of the radicals derived from the paraffins are formed from the name of the corresponding hydrocarbon by dropping the syllable *ane* and adding the termination *yl.* For example, the alcohol derived from propane, C_3H_8, is called propyl alcohol, C_3H_7OH. Radicals of this type are called *alkyl* radicals as they are present in alcohols.

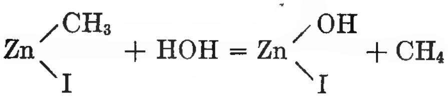
Methyl iodide can be obtained readily in a pure condition. It is a low-boiling, heavy liquid. In order to prepare methane from it, it is necessary to replace the iodine by hydrogen. This can be done in a number of ways. One method is to treat the compound with nascent hydrogen. When the gas is prepared by the action of a metal on an acid the hydrocarbon formed is contaminated with hydrogen. In order to avoid this, the iodide may be reduced by heating it with concentrated hydriodic acid in a sealed tube: —

$$CH_3I + HI = CH_4 + I_2$$

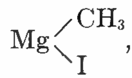
This is not a convenient laboratory method of preparing methane or other gaseous hydrocarbons which are formed in an analogous way from their iodine derivatives. It is a useful method, however, of replacing iodine by hydrogen in the case of liquids and solids when larger quantities may be handled in tubes of convenient size. The most satisfactory practical method of converting methyl iodide into methane, is to drop a solution of methyl iodide in alcohol onto a zinc-copper couple. The couple can be made by heating a mixture of three parts of granulated zinc with one part of powdered copper until the metals begin to alloy. In this form the metals are particularly active. The reaction consists in the formation of a compound of zinc and methyl iodide, which is subsequently decomposed by the alcohol itself, or by the water present in it. The reactions are as follows:



$$Zn + CH_3I = Zn\begin{matrix} / CH_3 \\ \backslash I \end{matrix}$$



$$Zn\begin{matrix} / CH_3 \\ \backslash I \end{matrix} + HOH = Zn\begin{matrix} / OH \\ \backslash I \end{matrix} + CH_4$$

By this method a slow and steady evolution of methane is produced. The gas contains a trace of methyl iodide vapor from which it must be separated. Magnesium may be used instead of zinc in the preparation of methane from methyl iodide. When the metal is warmed with the iodide a vigorous reaction takes place and magnesium methyl iodide,  $Mg\begin{matrix} / CH_3 \\ \backslash I \end{matrix}$, a colorous solid, is formed. With water this yields methane, magnesium hydroxide, and magnesium iodide.

18. Chemical Properties of Methane. — Methane is a very stable compound, and is inert when subjected to the action of most substances. The formation of methane as the result of the action of high heat on other hydrocarbons is further evidence of its stability. It is not affected by sulphuric, nitric, and other active acids, and can be heated with alkalies and powerful oxidizing agents without change.

When methane is heated with oxygen to 670° the mixture explodes, forming carbon dioxide and water-vapor. The kindling temperature of methane is higher than that of hydrogen or amorphous carbon. Methane burns with a flame which is only slightly luminous. Its heat of combustion is high on account of the fact that it contains such a large proportion of hydrogen. The percentage of hydrogen in methane is greater than that in any other hydrocarbon. It is for this reason a valuable fuel. It must be enriched, however, before being used as an illuminant.

The equation which represents the volume relations and the amount of heat evolved when methane burns in oxygen, is as follows: —

$$\begin{array}{lll} CH_4 + 2\,O_2 & = & CO_2 + 2\,H_2O + 213{,}500 \text{ cal.} \\ 1 \text{ vol.} + 2 \text{ vol.} & & 1 \text{ vol.} + 2 \text{ vol.} \end{array}$$

This equation means that one volume of methane reacts with two volumes of oxygen and forms one volume of carbon dioxide and two volumes of water-vapor. If the latter condenses to the liquid state, the contraction when methane is exploded is from three volumes to one volume. In the case of other gaseous hydrocarbons the contraction is different in amount. The change in volume which takes place when hydrocarbons are exploded with oxygen, serves as a means of identifying them, and is the basis for their determination in gas analysis. The equation also means that the amount of heat given off when 16 grams of methane are burned, is 213,500 calories.

Chlorine and bromine react with methane and form products in which a part or all the hydrogen is replaced by halogen. Mixtures of chlorine and methane explode when exposed to direct sunlight. Hydrochloric acid, carbon, and compounds containing carbon, hydrogen, and chlorine, are formed. The carbon is formed by the reaction,

$$CH_4 + 2\,Cl_2 = C + 4\,HCl$$

Reactions similar to this, in which chlorine removes all the hydrogen, are known in the cases of other hydrocarbons. When the violence of the reaction between chlorine and methane is reduced by mixing with the gases an inert gas, such as carbon dioxide, or by allowing the reaction to take place in diffused light, the hydrogen atoms in the hydrocarbon are replaced by chlorine. In this way compounds having the formulas CH_3Cl, CH_2Cl_2, $CHCl_3$, and CCl_4 are formed. The replacement of one element by another, as in these cases, is called *substitution.* The substances formed are called *substitution-products.* The reaction by which methyl chloride is formed takes place according to the equation,

$$CH_4 + Cl_2 = CH_3Cl + HCl$$

The substitution-products of methane are called monochlormethane, dichlormethane, trichlormethane, and tetrachlormethane. In general, in naming substitution-products there is added to the name of the hydrogen compound from which the product is derived, the name of the element which has replaced the hydrogen, together with a prefix to specify the number of atoms which enter into the compound. Thus, the substance with the formula CH_2Cl_2 is called dichlormethane. In the case of many simple compounds other names than those derived in the way just indicated are used. Dichlormethane is often called methylene chloride. As the group CH_2 is present in a number of compounds it has been given the name methylene.

Although chlorine and bromine react with methane and many other compounds and form substitution-products, iodine does not show this power except under exceptional circumstances. The three halogens resemble one another in chemical properties, but there is a marked decrease in activity as we pass from chlorine to iodine. Chlorine and bromine react with hydrogen with the evolution of heat, whereas under the same conditions hydrogen iodide is formed with the absorption of heat. As the process of substitution involves the formation of a compound of the halogen and hydrogen, it is evident that the marked difference between the activity of chlorine and bromine on one hand, and that of iodine on the other, is an important factor in the reaction. From this point of view the reaction by which methane may be prepared from methyl iodide and hydriodic acid can be more readily understood. The equation for the reaction,

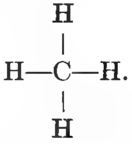
$$CH_3I + HI = CH_4 + I_2$$

is the reverse of the one by which substitution takes place, namely,

$$CH_4 + Cl_2 = CH_3Cl + HCl$$

In the case of iodine the stable condition when reaction takes place is the hydrocarbon and the free halogen. In the case of chlorine the reverse is true. We shall see later that hydrochloric acid and hydriodic acid are markedly different in the readiness with which they react with many organic compounds, and that the reactivity of the halogen atoms in organic compounds varies with the halogen.

19. Structure of Methane. — According to the structure theory of organic compounds, the molecule of methane consists of one carbon atom to which are united four hydrogen atoms. The graphic formula of the hydrocarbon is



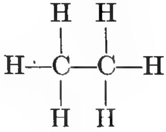
$$\begin{array}{c} \mathrm{H} \\ | \\ \mathrm{H{-}C{-}H}. \\ | \\ \mathrm{H} \end{array}$$

As a result of the study of many compounds the conclusion has been reached that the molecule is symmetrical; that is, all four hydrogen atoms bear the same relation to the carbon atom. It is conceivable that there might be differences in this relation among the hydrogen atoms. For example, one atom might be further removed from the carbon atom than the other hydrogen atoms, or be more loosely bound than the rest. An elaborate investigation of this point, which can not be discussed here, has shown that the hydrogen atoms in the molecule are symmetrically arranged with regard to one another and the carbon atom.

20. Ethane, C_2H_6, occurs in small quantities in natural gas and in solution in crude petroleum. It resembles methane in both chemical and physical properties, but is more readily liquified. Liquid ethane boils at − 90°.

Methods analogous to those used in making methane can be applied to the preparation of this hydrocarbon. It is usually prepared by treating an alcoholic solution of ethyl iodide, C_2H_5I, with the zinc-copper couple.

The structure of ethane is represented by the formula



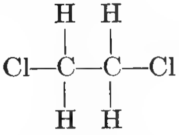
$$\begin{array}{ccccc} & \mathrm{H} & & \mathrm{H} & \\ & | & & | & \\ \mathrm{H}- & \mathrm{C} & - & \mathrm{C} & -\mathrm{H} \\ & | & & | & \\ & \mathrm{H} & & \mathrm{H} & \end{array}$$

This arrangement of the atoms is the only possible one if the assumption of the quadrivalence of carbon is accepted. There is, indeed, experimental evidence in favor of the correctness of this view. A method by which the hydrocarbon may be prepared shows that ethane is made up of two methyl (CH_3) groups. Methyl iodide and sodium react and form ethane and sodium iodide: —

$$2\,CH_3I + 2\,Na = CH_3 - CH_3 + 2\,NaI$$

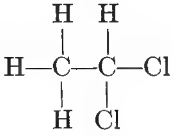
The simplest explanation of the change which takes place is that the metal removes the halogen atom from the iodide, and the methyl group which is formed unites with a second group to form ethane.

The view of the structure of ethane which has been reached in this way leads to the conclusion that all the six hydrogen atoms are alike in their relation to the carbon atoms. This has been found to be true, for although chlorethane, C_2H_5Cl, and other similar substitution-products have been made in a number of ways, no case of isomerism among mono-substitution-products has ever been discovered. The structure assigned to ethane does suggest, however, the possibility of the existence of two dichlorethanes, namely,



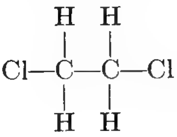
$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ Cl & - & C & - & C & - & Cl \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

and



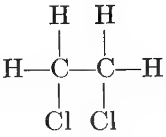
$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & Cl \\ & & | & & | & & \\ & & H & & Cl & & \end{array}$$

In one compound the chlorine atoms are united to different carbon atoms; in the other they are in combination with the same carbon atom. Two dichlorethanes are known, and we have reason to believe that they have molecular configurations in accordance with the formulas just given. From an examination of the graphic formulas of the dichlorethanes, it might appear that more than two compounds are possible. The formulas



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ Cl & - & C & - & C & - & Cl \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

and

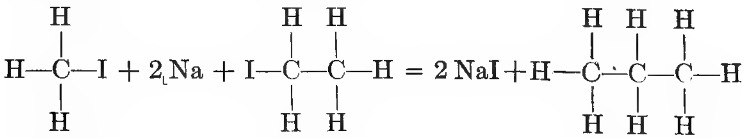


$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & Cl & & Cl & & \end{array}$$

appear to be different. This is not the case, however, for it will be remembered that all the hydrogen atoms in methane, and, therefore, in a methyl group, are alike in their relation to the carbon atom. This fact should be borne in mind in the study of more complicated substitution-products which will be considered later. The necessity of writing formulas on a plane leads to apparent differences which do not exist among the compounds themselves.

The existence of the dichlorethanes has been mentioned at this point as their consideration serves to emphasize the methods used in establishing structural formulas. If we take ethane for an example, the methods of preparing the hydrocarbon furnish facts which lead to a definite conclusion as to its structure. The conclusion reached in this way, however, must be tested further before it may be said to be well founded. We must deduce certain consequences which will follow if the view taken is the correct one. The more facts in accord with the theory, the more firmly is established the correctness of the assigned formula. It has been said that two dichlorethanes should exist if ethane has the formula assigned to it, and two are known. A study of the formula will lead to the conclusion that there should be two trichlorethanes, two tetrachlorethanes, one pentachlorethane, and one hexachlorethane. Just this number of chlorine substitution-products exist. These facts strengthen markedly the conclusion that the structure of ethane is that which has been assigned to it.

21. Propane, C_3H_8, is a gas and shows the same inertness to chemical reagents as is shown by the other hydrocarbons of the methane series. It can be condensed to a liquid, which boils at −17°. The methods of preparation and properties of propane lead to the conclusion that it is a methyl derivative of ethane. It can be prepared by the action of sodium on a mixture of methyl iodide and ethyl iodide: —

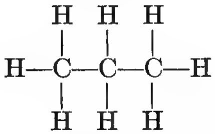


$$\mathrm{H{-}\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}{-}I + 2Na + I{-}\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}{-}\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}{-}H = 2\,NaI + H{-}\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}{-}\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}{-}\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}{-}H}$$

In this reaction the iodine atom in ethyl iodide is replaced by a methyl group. Reactions similar to this are much used in the synthesis of organic compounds. The building up of hydrocarbons in this way was first accomplished by Wurtz, a French chemist, in 1855. The method is usually called the Wurtz synthesis.

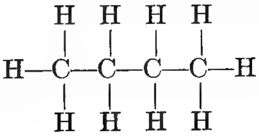
Propane prepared in this way is mixed with ethane, which is formed by the action of sodium on methyl iodide, and with butane, C_4H_{10}, which results from the action of the metal on ethyl iodide. Propane is obtained in pure condition by the action of the zinc-copper couple on propyl iodide.

22. Butanes, C_4H_{10}. — There are two hydrocarbons which have the composition represented by the formula C_4H_{10}, and according to the structure theory there should be only two. We can consider the butanes as derived from pentane by the replacement of one hydrogen atom by a methyl group, just as we considered ethane as methyl methane, and propane as methyl ethane. As all the hydrogen atoms in ethane are alike, but one methyl substitution-product and, accordingly, one propane, is possible. Let us consider the possibilities if we replace one hydrogen atom in propane by a methyl group. The formula of propane is

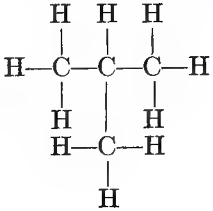


$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

An examination of the relation of the hydrogen atoms to the molecule shows that there is opportunity for isomerism. The hydrogen atoms which are joined to the end carbon atoms are alike in their position in the molecule. The two atoms which are in combination with the central carbon atom are alike, but differ from the other six hydrogen atoms in their relation to the molecule. It is evident, therefore, that two methyl derivatives are possible, and these should have the formulas,

(1) 

$$\begin{array}{ccccccccccc} & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & \end{array}$$

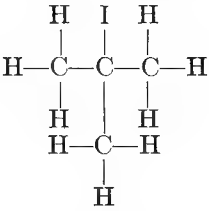
and (2) 

The substance having the structure represented by the first formula is called normal butane. The second formula is assigned to isobutane. Hydrocarbons in which the carbon atoms are linked in what is called a chain, that is, where no carbon atom is joined to more than two other carbon atoms, are called *normal hydrocarbons.* When a carbon atom is joined to three other carbon atoms in the molecule, this fact is shown by prefixing to the name of the hydrocarbon the syllable *iso,* which is derived from the word isomer.

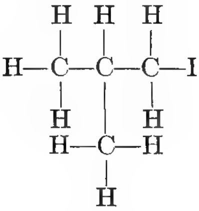
Normal butane occurs in crude petroleum. It is a gas which can be readily condensed to a liquid, which boils at 1°. It can be prepared by the action of sodium on ethyl iodide. Its synthesis in this way leads to the conclusion that it has the structure represented by formula (1) above. The formula is usually written in the form $CH_3CH_2CH_2CH_3$.

Isobutane does not occur in nature. It is prepared by the action of zinc and water on the butyl iodides of the formulas

(1)



and (2)



The reactions are analogous to the ones by which methane is made from methyl iodide and the zinc-copper couple. In the case of these iodides, however, zinc alone is capable of bringing about the reaction. Such formulas as the above are usually written, for convenience, in a more condensed form. In the molecule represented by the formula (1) there is one carbon atom to which are joined three methyl groups and an iodine atom. This fact is shown by the formula $(CH_3)_3CI$. Formula (2) can be written $(CH_3)_2CH.CH_2I$. It is important that the student should understand clearly the significance of these condensed formulas, as such formulas are generally used to express the structure of organic compounds.

23. Pentanes, C_5H_{12}. — As the number of carbon atoms in hydrocarbons increases, the opportunity for isomerism increases.

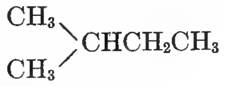
The number of possible isomers and the arrangement of the atoms in the several molecules can be determined by the application of the principle made use of in deducing the butanes. The hydrocarbons of any formula may be considered as derived from the hydrocarbons containing one less carbon atom, by the replacement of one hydrogen atom by a methyl group. Let us apply this method to determine the number of hydrocarbons of the formula C_5H_{12} which are possible. The butanes have the formula

$$\text{(I)}\ \overset{(1)}{CH_3}\ \overset{(2)}{CH_2}\ \overset{(2)}{CH_2}\ \overset{(1)}{CH_3}\ \text{and}\ \text{(II)}\ \overset{(3)}{(CH_3)_3}\ \overset{(4)}{CH}$$

In normal butane (formula I) there are two kinds of hydrogen atoms, when we consider the position of these atoms in the molecule. All six atoms joined to the end carbons are alike and are marked (1). The other hydrogen atoms are like one another but differ in their position from those which are joined to the end carbon atoms. These are marked (2). In isobutane (formula II) the nine hydrogen atoms in the three methyl groups are alike. The atom marked (4) differs from the others in position. It is evident that formulas for hydrocarbons containing five carbon atoms can be written if we replace one hydrogen atom in the butanes by a methyl group. All the possible isomers should be obtained in this way, if the different hydrogen atoms are replaced in turn. The derived formulas are obtained by replacing the hydrogen atoms marked (1), (2), (3), (4), respectively, by methyl.

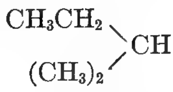
(1). $CH_3CH_2CH_2CH_2CH_3$

(2).



$$\begin{array}{l} CH_3\diagdown \\ \qquad\ \ CHCH_2CH_3 \\ CH_3\diagup \end{array}$$

(3).



$$\begin{array}{l} CH_3CH_2\diagdown \\ \qquad\qquad\ CH \\ \quad (CH_3)_2\diagup \end{array}$$

(4). $(CH_3)_3CCH_3$

As the formulas are written they appear to represent four distinct arrangements of the atoms. By a careful examination of the ones marked (2) and (3) it will be seen that they are alike. In each formula there is a carbon atom to which is joined one hydrogen atom, two methyl groups, and one ethyl group. It is thus seen that according to the structure theory there should be three pentanes. Three hydrocarbons of the formula C_5H_{12} are known.

Confusion arising from the different ways of writing the same formula can be avoided by naming the hydrocarbons according to a definite method. One method used is as follows: The hydrocarbon is considered as a compound derived from methane by the replacement of one or more hydrogen atoms by radicals. In selecting the atom which is to be considered as the carbon atom of methane, that atom is chosen which is united with the largest number of carbon atoms. According to this method, the compound which has the structure represented by formula (2) and formula (3) is dimethyl-ethyl-methane. Formula (4) is tetramethyl-methane.

The three pentanes, which are known, can be prepared by methods which indicate that they have the structures represented by the formulas deduced above. These hydrocarbons are not appreciably affected by acids, bases, or oxidizing agents. They react with chlorine and bromine, and burn in the air. Normal pentane boils at 36.4°; isopentane, or dimethyl-ethyl-methane at 30°, and tetramethyl-methane at 9.5°. It has been observed as the result of the study of a number of hydrocarbons that isomers have different boiling-points, and, in general, the isomer with the longer chain has the higher boiling-point. In normal pentane there is a chain of five carbon atoms, in isopentane a chain of four, and in tetramethyl-methane a chain of three.

HIGHER MEMBERS OF THE METHANE SERIES

24. As the number of carbon atoms in the hydrocarbons increases, the number of isomers which are possible according to the structure theory increases. It has been calculated that there should be five compounds of the formula C_6H_{14}, nine of the formula C_7H_{16}, seventy-five of the formula $C_{10}H_{22}$, eight hundred and two of the formula $C_{13}H_{28}$, and so on. But few of the compounds which are indicated by the theory are known. Chemists have, however, carried the study of the isomerism among these hydrocarbons far enough to feel convinced that the theory is in accord with the facts. The five hexanes, which have the formula C_6H_{14}, have been prepared. Five of the nine possible heptanes and a smaller number of isomers of higher hydrocarbons are known. Certain experimental difficulties are encountered when an attempt is made to synthesize hydrocarbons with the more complex arrangement of atoms.

Many hydrocarbons which have the normal structure are known. Such compounds can be prepared readily, and the fact that many of them occur in petroleum has led to their study. A table of the composition and the more important physical properties of a number of the normal hydrocarbons of the methane series is here given.

NORMAL HYDROCARBONS OF THE METHANE SERIES

Formula	Name	Melting-point	Boiling-point	Specific Gravity
CH_4	Methane	−186°	−160°	0.415 (at −160°)
C_2H_6	Ethane	−172.1°	−93°	0.446 (at 0°)
C_3H_8	Propane		−45°	0.536 (at 0°)
C_4H_{10}	Butane		1°	0.600 (at 0°)
C_5H_{12}	Pentane		36.4°	0.627 (at 14°)
C_6H_{14}	Hexane		68.9°	0.658 (at 20°)
C_7H_{16}	Heptane		98.4°	0.683 " "
C_8H_{18}	Octane		125.6°	0.702 " "
C_9H_{20}	Nonane	−51°	149.5°	0.718 " "
$C_{10}H_{22}$	Decane	−31°	173°	0.730 " "
$C_{11}H_{24}$	Undecane	−26°	194°	0.774 at melting-point.
$C_{12}H_{26}$	Dodecane	−12°	214.5°	0.773 " " "
$C_{14}H_{30}$	Tetradecane	4°	252.5°	0.775 " " "
$C_{16}H_{34}$	Hexadecane	18°	287.5°	0.775 " " "
$C_{20}H_{42}$	Eicosane	37°	205°[1]	0.778 " " "
$C_{21}H_{44}$	Heneicosane	40°	215°[1]	0.778 " " "
$C_{23}H_{48}$	Tricosane	48°	234°[1]	0.779 " " "
$C_{31}H_{64}$	Hentriacontane	68°	302°[1]	0.781 " " "
$C_{35}H_{72}$	Pentatricontane	75°	331°[1]	0.782 " " "
$C_{60}H_{122}$	Hexacontane	101°		

An inspection of the table shows that the hydrocarbons which contain more than four carbon atoms are named from the Greek numerals which signify the number of carbon atoms in the molecule. Each compound differs in composition from the next member in the series by CH_2. This results from the fact that such a series can be built up by replacing one hydrogen atom by a CH_3 radical. Many such series of compounds are known, in which the members have similar chemical properties, and differ in composition by CH_2. Such relationship is known as *homology* and the compounds constitute an *homologous* series. Any compound in the series is said to be a *homologue* of any other compound in the series.

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[1] At 15 mm. pressure.

While the chemical properties of the members of an homologous series are, in general, the same, an increase in the number of carbon atoms is associated with a gradual change in physical properties. It will be observed from the table that the first four hydrocarbons are gases at the ordinary temperature; from pentane to hexadecane they are liquids, and the compounds which contain more than sixteen carbon atoms are solids. An increase in molecular weight corresponding to CH_2 brings about an increase in boiling-point, which grows less as the molecular weight of the hydrocarbon increases. Thus, between the boiling-points of butane and pentane there is a difference of 35.4°, between hexane and heptane 29.6°, and between undecane and dodecane 20.5°. Similar facts are observed in other homologous series.

25. Heat of Combustion and Heat of Formation. — By the heat of combustion of a compound is meant the amount of heat which is set free when one gram-molecule of the substance is burned to carbon dioxide and water. The heats of combustion of a few of the methane hydrocarbons are given in the following table. The heat unit used is the large calorie (1000 gram calories).

	Heat of Combustion	Difference
CH_4	213.5 Cal.	158.8 Cal.
C_2H_6	372.3 "	156.1 "
C_3H_8	528.4 "	158.8 "
C_4H_{10}	687.2 "	159.9 "
C_5H_{12}	847.1 "	

It is seen that the increase in the heat of combustion in the homologous series is nearly constant for an increase of CH_2. An examination of a number of such series brings out the fact that a difference in composition in CH_2 corresponds, on the average, to a difference of 158 Cal. in the heat of combustion. It is thus possible to calculate approximately the amount of heat developed when a compound is burned, provided the heat of combustion of a homologue is known.

The heat of formation of a compound is the amount of heat set free when one gram-molecule of the substance is formed from its elements. It is impossible to determine directly the heat of formation of an organic compound, but this quantity can be calculated from the heat of combustion of the elements which make up the compound and the heat of combustion of the compound itself. Thus, the heat of combustion of amorphous carbon (12 grams) is 97 Cal., and of hydrogen (1 gram) is 34.2 Cal. The heat which is set free, accordingly, when 12 grams of carbon and 4 grams of hydrogen are burned, equals 97 Cal. + 4 (34.2 Cal.) = 233.8 Cal. The heat of combustion of methane (16 grams) is 213.5 Cal. The difference between these two quantities, 20.3 Cal., is taken as the heat of formation of methane, that is, the amount of heat which is liberated in the union of carbon and hydrogen to form methane.

The heat of formation of the paraffin hydrocarbons is positive, that is, heat is given off in their formation. They are exothermic compounds. The heats of formation of some hydrocarbons are negative. This means that the compounds when burned produce more heat than is produced when the equivalent weights of carbon and hydrogen are burned. Such compounds are called endothermic.

26. Chemical Properties of the Paraffins. — The paraffin hydrocarbons are characterized by their great inertness to chemical reagents. By the long-continued action of nitric acid and of sulphuric acid the higher members of the series, that is, those containing a large number of carbon atoms, are converted into derivatives which contain nitrogen and sulphur, respectively. For example, when hexane is heated with fuming nitric acid for 40 hours, about ten per cent of the hydrocarbon is converted into nitrohexane, $C_6H_{13}.NO_2$. The reaction is represented by the equation,

$$C_6H_{14} + HONO_2 = C_6H_{13}.NO_2 + H_2O$$

With fuming sulphuric acid under similar conditions sulphonic acids are formed: —

$$C_6H_{14} + HO.SO_2OH = C_6H_{13}.SO_2.OH + H_2O$$

The substances formed in this way belong to important classes of compounds which will be discussed later. The nitro and sulphonic acid derivatives of the paraffins are usually made by other reactions.

Chlorine and bromine react with the hydrocarbons to form substitution-products. As mixtures of compounds are obtained in this way the reactions are not often used in the preparation of halogen derivatives.

27. Detection of the Paraffins. — The identification of the paraffins is difficult on account of the lack of definite analytical tests. The paraffins are characterized by .their inertness. They can be shaken with fuming nitric acid without appreciable change. They are insoluble in concentrated sulphuric acid and are not attacked by it. The liquid hydrocarbons react slowly with bromine; a solution of the halogen in the hydrocarbon retains its color for some time. As reaction takes place hydrobromic acid is evolved. The hydrocarbons are insoluble in water and float. They dissolve in alcohol and benzene.

The properties which have been stated are those of the pure hydrocarbons. Many commercial mixtures such as gasoline, benzine, kerosene, etc., consist largely of paraffins. Such mixtures when subjected to the tests stated above react to some extent, on account of the fact that they contain small quantities of other more reactive hydrocarbons. When these have entered into reaction the paraffin hydrocarbons which are left exhibit their characteristic inertness.

28. Petroleum. — Petroleum is the most important source of the paraffin hydrocarbons. The oil is widely distributed, and is found in large quantities in America and Russia. The most productive regions in the United States are California, Illinois, Pennsylvania, Texas, Kansas, Indian Territory, and Oklahoma.

Crude petroleum is an oily liquid which varies in color from amber to black. Some varieties are red, brown, or orange, and by reflected light often appear greenish in tint. Most American oils consist largely of paraffins. The hydrocarbons from methane to the one having the composition $C_{27}H_{56}$ have been isolated from these oils. In addition, there are present small quantities of members of the ethylene (**29**) and benzene (**342**) series, which have the general formulas C_nH_{2n}, and C_nH_{2n-6}, respectively. The Russian petroleum consists largely of hydrocarbons, called naphthenes (**377**), which are isomeric with the hydrocarbons of the ethylene series, but differ from them in chemical properties.

The crude oil is purified and separated into a number of commercial products by distillation. The distillate is separated into fractions according to specific gravity. The first fraction, which is called crude naphtha, is collected until the specific gravity of the distillate is .729. The "burning oil distillate" then follows until the gravity equals .790. The high-boiling oils which are used for lubrication, are then distilled until a residue of coke is left. In order to purify the oils further the separate fractions are agitated, in turn, with concentrated sulphuric acid, water, and a dilute solution of sodium hydroxide, and are finally washed with water. When sulphur compounds, which give an offensive odor to the oil, are present, distillation is carried out in the presence of copper oxide; this removes the carbon bisulphide, methyl sulphide, and other impurities present.

The crude naphtha is redistilled and separated, according to the specific gravity of the distillates, into a number of fractions to which special names are given. These fractions are called in the order of increasing gravity and boiling-points cymogene, rhigolene, petroleum ether, naphtha, benzine, and ligroin. Gasoline is a name given to a product which contains the hydrocarbons found in naphtha, benzine, and ligroin. It is to be noted that all these names are given to mixtures of varying composition, and that there are various grades of naphthas, benzines, etc., which are sold according to their specific gravities. In the trade, density is determined by a hydrometer invented by Baumé, which registers in so-called degrees the density of a liquid. A 70° naphtha is one which has the specific gravity corresponding to 70° on the Baumé hydrometer. The petroleum ether and ligroin used in chemical laboratories as solvents boil approximately at $40° = 70°$ and $70° = 100°$, respectively.

The "burning oil distillate" is fractionated into various grades of *kerosene*. As these oils are used for burning in lamps the test applied in the case of kerosene is one which determines its safety when used for this purpose. The temperature is determined to which the oil must be heated to give sufficient vapor to produce a momentary flash when a flame is brought near its surface. This temperature is called the *flash-point*. The *fire-test* is the temperature at which the oil gives off enough vapor to maintain a continuous flame if ignited.

The flash-point and fire-test of a sample of kerosene depend, to some extent, on the particular form of apparatus used. For this reason, the laws which specify the legal limits for these numbers usually include statements in regard to the way in which the tests should be made. In the United States each state has its own standard. Most, however, require a flash-point of at least 110° F. and a fire-test of from 110° F. to 150° F.

The product which is left after the crude naphtha and kerosene have been removed, is distilled and fractionated into the different grades of lubricating oils. The higher boiling oils are chilled and *paraffine* crystallizes out. *Vaseline* or petrolatum is made from the residuum of oils with high boiling-points, which are distilled in a vacuum.

In order to increase the yield of the more valuable light oils, the stills in which the distillation is carried out are so constructed that a part of the vapor is condensed and returned to the boiling oil. This is heated to such a high temperature that when the condensed hydrocarbons come in contact with it they are decomposed into compounds of lower molecular weight. In addition to paraffins, hydrocarbons of the ethylene series, C_nH_{2n}, are formed in this way. As a result of this process, which is called *cracking*, refined petroleum products often contain compounds which were not present in the crude oil. Samples of gasoline will show some of the characteristic reactions of the ethylene hydrocarbons, although they consist essentially of paraffins.

PROBLEMS

1. Write equations for the reactions which take place in the general methods of preparing hydrocarbons of the methane series.

2. Write the graphic formulas of the hexanes, and name each compound as a substitution-product of methane.

✓ 3. Write equations for reactions by which the three pentanes may be prepared (*a*) from organic acids and (*b*) by the Wurtz synthesis.

✓ 4. Starting with methyl alcohol, CH_3OH, ethyl alcohol, C_2H_5OH, and any inorganic compounds required, write equations for reactions by which the following may be prepared: (*a*) CH_4, (*b*) C_2H_6, (*c*) C_3H_8, (*d*) $n-C_4H_{10}$.

5. When 40 cc. of a sample of air which contained methane was exploded, the residual gas after the removal of carbon dioxide measured 32 cc. What was the percentage by volume of methane in the mixture?

6. Write an equation which indicates the volume relations involved when ethane is burned. If carbon dioxide and water are removed after the reaction, what contraction in volume takes place in the volume of the gases?

7. From the molecular formula of ethane calculate the weight of 1 liter of the gas at (*a*) 0° and 760 mm., (*b*) at 20° and 750 mm.

CHAPTER III

HYDROCARBONS OF THE ETHYLENE SERIES

29. Ethylene, C_2H_4, is the first member of the homologous series of hydrocarbons having the composition represented by the general formula C_nH_{2n}. Repeated efforts have failed to prepare a compound of this series with but one carbon atom. The homologues of ethylene contain two less hydrogen atoms than the hydrocarbons in the methane series with the same number of carbon atoms. Thus, we have propane, C_3H_8, butane, C_4H_{10}, and hexane, C_6H_{14}, and propylene, C_3H_6, butylene, C_4H_8, hexylene, C_6H_{12}, etc. The hydrocarbons of this series are named, as illustrated, by replacing the syllable *ane* in the name of the saturated compound by the termination *ylene*, or by changing the vowel *a* in the termination to *e*. The compound having the formula C_7H_{14} is called heptylene or heptene.

Ethylene was originally called olefiant (meaning oil forming) gas, on account of the fact that it formed an oil when it reacted with chlorine. For this reason homologues of ethylene are often called *olefines*.

Ethylene is frequently formed when non-volatile organic compounds are subjected to destructive distillation, or when hydrocarbons are heated to such a temperature that they undergo decomposition. The ethylene found in coal-gas and in carbureted water gas is produced in this way. Natural gas also contains a small percentage of this hydrocarbon. The luminosity of illuminating gas is due in part to the presence of ethylene, which is present in the gas to the extent of from four to five per cent.

Ethylene is a colorless gas which possesses a peculiar, sweetish odor. One volume of water dissolves one-fourth volume of the gas, and one volume of alcohol about three and one-half volumes. It is much less stable toward heat than methane. At about 400° it decomposes; methane, acetylene, benzene, and other hydrocarbons are formed. Ethylene burns with a brilliant flame. A mixture of the gas and air explodes violently when ignited.

Theoretically, ethylene could be prepared by removing two hydrogen atoms from ethane. As the removal of hydrogen atoms alone from a compound cannot usually be effected, the difficulty is overcome by first replacing hydrogen by halogen and subsequently removing the latter. The halogens have a great affinity for metals, and when organic compounds which contain chlorine, bromine, or iodine are brought into contact with the more active metals, halides of the metals are formed. A typical reaction is represented by the following equation: —

$$C_2H_4Br_2 + Zn = C_2H_4 + ZnBr_2$$

A second method of preparing the hydrocarbon illustrates another principle which is important, as it can be applied to the preparation of many compounds which show the behavior of ethylene. When an alkyl halide, ethyl bromide for example, is heated with an alcoholic solution of potassium hydroxide, the base removes one hydrogen and one halogen atom. In this way ethylene can be prepared from ethyl bromide: —

$$C_2H_5Br + KOH(\text{in alcohol}) = C_2H_4 + KBr + H_2O$$

If the potassium hydroxide is dissolved in water the halogen atom is replaced by the hydroxyl group, and alcohol is formed.

A third method of preparation is important on account of its general applicability. This consists in heating alcohol with a dehydrating agent. Under these conditions the elements of water are eliminated from the alcohol and ethylene results: —

$$C_2H_5OH + (\text{a dehydrating agent}) = C_2H_4 + H_2O$$

To bring about the removal of water from the alcohol concentrated sulphuric acid or phosphorus pentoxide can be used. When ethylene is prepared by this method a mixture of alcohol and sulphuric acid is heated to about 170°-180°. The reaction takes place in two stages: When the alcohol and the acid are mixed they react according to the equation: —

$$C_2H_5OH + H_2SO_4 = C_2H_5.HSO_4 + H_2O$$

A compound, acid ethyl sulphate, commonly called ethyl sulphuric acid, is formed. This substance subsequently decomposes thus: —

$$C_2H_5.HSO_4 = C_2H_4 + H_2SO_4$$

30. Ethylene and its homologues are much more reactive than the hydrocarbons of the methane series. This activity is due to the fact that while two carbon atoms have the capacity of holding in combination six univalent atoms, as in the case of ethane, in ethylene but four such atoms are present. The compound is, therefore, said to be *unsaturated*. When it is brought in contact with certain elements or compounds, ethylene forms new compounds by adding atoms or groups of atoms. In this process *two* univalent atoms or groups are added to the hydrocarbon, and a *saturated* compound is formed, that is, a compound in which the two carbon atoms hold in combination six atoms or groups — the maximum number possible on the assumption that carbon has the valence of four.

When ethylene is passed into bromine, direct combination takes place and ethylene bromine is formed: —

$$C_2H_4 + Br_2 = C_2H_4Br_2$$

Addition-products are also formed with chlorine and with iodine. The difference in the readiness with which ethylene chloride and ethylene iodide are formed illustrates clearly the difference in the activity of the two halogens. In the case of chlorine the reaction must be carried out in the dark and the temperature must be kept low. Even in diffused light ethylene burns in chlorine with a smoky flame. The reaction is analogous to that between methane and chlorine. It takes place essentially according to the equation,

$$C_2H_4 + 2\,Cl_2 = 2\,C + 4\,HCl$$

The influence of sunlight on reactions in which the halogens are involved is marked. It will be seen later that the course of many such reactions is determined by this factor. The student will remember that sunlight brings about the union of chlorine and hydrogen.

Ethylene does not react so readily with iodine as with chlorine. When the gas is passed into a warm solution of iodine in alcohol, the two substances unite slowly.

At 100° ethylene reacts with concentrated hydriodic acid, and ethyl iodide is formed: —

$$C_2H_4 + HI = C_2H_5I$$

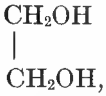
An analogous reaction takes place less readily with hydrobromic acid, but with hydrochloric acid no compound is formed. The difference in reactivity of the halogens and halogen acids as shown in their behavior with ethylene, is, in general, characteristic of these substances. Chlorine is the most active halogen and hydriodic acid is the most active acid.

Ethylene is absorbed slowly by concentrated sulphuric acid, and ethyl sulphuric acid is formed: —

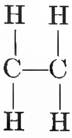
$$C_2H_4 + H_2SO_4 = C_2H_5.HSO_4$$

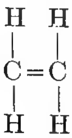
It will be remembered that at about 170° ethyl sulphuric acid undergoes decomposition into ethylene and sulphuric acid.

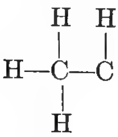
When a mixture of ethylene and hydrogen is passed over finely divided nickel at about 300° the hydrocarbon is reduced to ethane; carbon and methane are also formed as the result of the decomposition of a part of the ethylene.

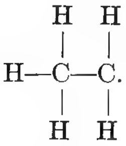
Whereas the paraffin hydrocarbons resist to a high degree the action of oxidizing agents, ethylene and its homologues are oxidized readily. Aqueous solutions of chromic acid oxidize ethylene to carbon dioxide. Neutral or alkaline solutions of potassium permanganate form, along with other substances, glycol,  $\begin{array}{l}CH_2OH\\ |\\ CH_2OH,\end{array}$ the reaction bringing about the addition of two hydroxyl groups to ethylene.

31. Structure of Ethylene. — The property possessed by ethylene of forming compounds by direct addition with other substances, is observed in the case of many other organic compounds. In writing graphic formulas of such unsaturated compounds, an attempt is made to represent the structure of molecules which should be capable of such reactions. The possible configurations of a molecule of ethylene may be represented by these formulas: —

(1) 
$\mathrm{HC{-}CH}$ with H above and below: $\mathrm{H_2C{-}CH_2}$

(2) 
$\mathrm{H_2C{=}CH_2}$

(3) 
$\mathrm{H_3C{-}CH}$

In formula (1) the carbon atoms are represented as having a valence of three. While it has not been proven that carbon can not have this valence, no compound is known the properties of which make it necessary to assume the existence of a trivalent carbon.[1] A more positive argument against the correctness of this formula may be drawn from the following considerations. If we assume trivalent carbon atoms in ethylene, there is no apparent reason why compounds should not exist which contain but one atom with this valence, for example  $\mathrm{H_3C{-}CH_2}$. Such a compound would be unsaturated and would unite with but one univalent atom. Further, a hydrocarbon which contained one trivalent carbon atom would contain an uneven number of hydrogen atoms. These conclusions can be tested by experiment. Efforts which have been made to prepare a hydrocarbon containing an uneven number of hydrogen atoms, have been without success. A study of many compounds has shown that when atoms or groups are added to unsaturated compounds, an *even* number of univalent atoms, or their equivalents, enter into combination. This means that all such compounds contain two, four, etc., carbon atoms which have the power to unite with other atoms. The phenomenon of unsaturation results as a consequence of the relation between two atoms of carbon. This fact is indicated graphically in the case of ethylene by writing the formula as represented by formula (2) above. In this formula each line represents a combining power of the carbon atoms, which are shown to be quadrivalent. The double line between the two carbon atoms indicates that these atoms are unsaturated and have the power to add two univalent atoms or groups. Atoms joined in this way are said to be doubly linked, or to be connected by a *double bond.*

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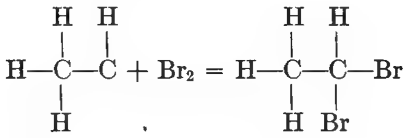
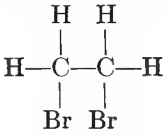
[1] A compound has been described recently the reactions of which can be explained best on the assumption that it contains a trivalent carbon atom. The conclusions stated above are drawn from the study of many compounds.

The third formula given above must be rejected as it can not be used to interpret the reactions of ethylene. It represents one carbon atom as bivalent. The addition of bromine to a substance having such a structure should, evidently, lead to the formation of a compound in which the two added atoms are joined to the same carbon atom,



$$\begin{array}{ccccc} & & H & & H \\ & & | & & | \\ H & - & C & - & C \\ & & | & & \\ & & H & & \end{array} + Br_2 = \begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & Br \\ & & | & & | & & \\ & & H & & Br & & \end{array}$$

The reactions of ethylene bromide, which is formed by the addition of bromine to ethylene, lead to the conclusion that its structure should be represented by the formula



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & Br & & Br & & \end{array}$$

in which each carbon atom is united to a bromine atom. The structural formula assigned to ethylene is, accordingly, $H_2C=CH_2$. The two lines (double bond) written between the carbon atoms serve to represent graphically the fact that the two carbon atoms thus connected possess what might be called latent affinities, which come into play when the compound is brought into contact with certain elements or compounds. Each of these unsaturated carbon atoms has the power to add to itself one univalent atom or group of atoms. When addition takes place, we say the double bond is broken. One of the bonds holds the carbon atoms in combination. The "breaking" of the second bond furnishes each of the two carbon atoms with a free affinity which serves to hold in combination the added atoms.

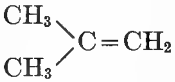
A mechanical interpretation of this hypothesis would lead to the view that in ethylene the carbon atoms are held together by two of the affinities of each atom, while in ethane but one of the affinities of each carbon atom serves this purpose. We might conclude from this that in the unsaturated compound a firmer union exists between the two carbon atoms, and that it would take more energy and more powerful reagents to separate them. The facts are not in accord with this conclusion. Ethane is a very stable compound and resists such energetic reagents as active oxidizing agents. It is very difficult to break a chain of saturated carbon atoms. On the other hand, oxidizing agents react readily with unsaturated compounds, and in many cases the carbon chain is broken at the double bond and two or more compounds are formed. The action of chromic acid on ethane and ethylene is an example. In the case of the saturated compound there is no action. Ethylene, however, is converted into carbon dioxide. The relation between the heats of formation of the saturated and unsaturated hydrocarbons, which will be discussed presently, throws much light on the nature of single and double linking between carbon atoms.

32. Propylene, C_3H_6. — The hydrocarbon of this series which contains three carbon atoms is called propylene. It may be considered as derived from ethylene by the replacement of one hydrogen atom by a methyl group. As the four hydrogen atoms in ethylene are alike, there is no opportunity for isomerism. The structural formula of propylene is $CH_3.CH=CH_2$. The compound is a gas. It can be prepared by methods which are analogous to those used to prepare ethylene. For its preparation propylene bromide, $C_3H_6Br_2$, propyl iodide, C_3H_7I, or propyl alcohol, C_3H_7OH, may be used. It will be remembered that two isomeric mono-substitution-products of propane are possible. For example, two iodides are known; normal propyl iodide, $CH_3CH_2CH_2I$, and isopropyl iodide, $CH_3.CHI.CH_3$. The fact that both compounds yield propylene when heated with an alcoholic solution of potassium hydroxide shows that in the formation of the unsaturated hydrocarbon the hydrogen and iodine atoms which are removed are joined to adjacent carbon atoms in the propyl iodides. A study of a large number of substances has shown that when a double bond is established by removing two atoms or groups from a saturated compound, the carbon atoms which become unsaturated as the result of such removal are joined to each other.

33. Butylenes, C_4H_8. — Three butylenes are possible according to the structure theory and three are known. The formulas may be written by replacing a hydrogen atom in propylene by a methyl group. Propylene has the formula $CH_3.CH=CH_2$. It is evident that the hydrogen atoms joined to each of the carbon atoms bear different relations to the molecule. The formulas for the possible butylenes are as follows:

(1) $CH_3CH_2CH=CH_2$

(2)



$$\begin{matrix} CH_3 \searrow & \\ & C=CH_2 \\ CH_3 \nearrow & \end{matrix}$$

(3) $CH_3CH=CHCH_3$

The three compounds are known. The one to which the first formula is assigned is called normal butylene; the second is isobutylene. In order to make clear the structure of hydrocarbons in this series they are often named as derivatives of ethylene. The butylene which has the structure represented by formula (2) is called unsymmetrical dimethyl-ethylene, and that represented by formula (3), symmetrical dimethyl-ethylene.

The methods of preparing these hydrocarbons, and their reactions, are in accord with the three formulas which have been assigned to them. They resemble ethylene in the ability to form compounds by direct addition with the halogens, halogen acids, sulphuric acid, etc.

They readily undergo *polymerization* when treated with moderately dilute sulphuric acid or with zinc chloride; that is, two or more molecules of butylene form new compounds by addition to each other. From butylene, C_4H_8, can be prepared in this way dibutylene, C_8H_{16}, which is an octylene, and tributylene, $C_{12}H_{24}$, which is a dodecylene. This polymerization is, no doubt, due to the unsaturation produced by the double bond, although the reaction is not shown by ethylene.

HIGHER MEMBERS OF THE ETHYLENE SERIES

34. A number of homologues of ethylene are known. Five isomeric pentylenes have been prepared. These hydrocarbons, which contain five carbon atoms, are usually called amylenes as they are prepared from the amyl alcohols, C_5H_7OH. The following table gives a list of some of the members of this series. The boiling-points given are those of the normal hydrocarbons.

NORMAL HYDROCARBONS OF THE ETHYLENE SERIES

Name	Formula	Boiling-point	Name	Formula	Boiling-point
Ethylene	C_2H_4	−103°	Heptylene	C_7H_{14}	98°
Propylene	C_3H_6	−48.5°	Octylene	C_8H_{16}	124°
Butylene	C_4H_8	−5°	Nonylene	C_9H_{18}	153°
Amylene	C_5H_{10}	35°	Decylene	$C_{10}H_{20}$	172°
Hexylene	C_6H_{12}	68°	Undecylene	$C_{11}H_{22}$	195°

These hydrocarbons can be prepared by the methods described when ethylene was considered. In their chemical reactions they also resemble the typical member of the series. In the addition of such substances as hydriodic acid and sulphuric acid to the unsymmetrical hydrocarbons, that is, those which have different arrangements of atoms on either side of the double bond, there is opportunity for the formation of isomeric compounds. Thus, when hydriodic acid and propylene unite, it is possible that the addition may take place in two ways. In one case the addition of the iodine atom to the central carbon atom and of hydrogen to the end carbon atom would yield isopropyl iodide, $CH_3.CHI.CH_3$. If the iodine were to add to the end of the chain propyl iodide, $CH_3.CH_2.CH_2I$, would result. Propylene and hydriodic acid form but one addition-product and this is isopropyl iodide. In a number of cases addition takes place in a similar manner, that is, the acid radical, I, SO_4H, etc., joins itself to the carbon atom to which is united the smaller number of hydrogen atoms. In general, the negative atom or group unites with the more positive carbon atom (**99**). When, however, there is no marked difference between the carbon atoms, the two possible isomeric compounds are formed; under these circumstances the concentration of the reacting substances and the temperature determine the relative proportions of the isomers formed (**217**).

35. Identification of Hydrocarbons of the Ethylene Series. — The most characteristic reactions of substances containing the double bond are, perhaps, the addition of bromine, and the reducing action on a neutral solution of potassium permanganate. There are substances more highly unsaturated than ethylene, and others which do not contain a double bond, which react with these reagents in the way in which compounds containing a double bond react. If these are excluded by proper tests — and we shall see later how this is to be done in most cases — a positive test of an unknown substance with bromine and potassium permanganate is a strong indication of the presence in it of a double bond.

The test with bromine is carried out by treating a solution of the compound in carbon tetrachloride, CCl_4, or some other solvent which is not affected by the halogen, with a solution of bromine in the solvent used to dissolve the substance under examination. A reaction is indicated by the disappearance of the color produced by the bromine. If this does not take place in a few minutes the solution should be gently heated. In the case of a double-bonded compound the reaction takes place as the result of addition and no hydrobromic acid is formed. If this gas is produced it is evident that substitution has taken place, and the test fails to give any evidence as to the presence of an unsaturated compound. The presence of hydrobromic acid can be shown by blowing one's breath across the mouth of the tube in which the test is made; if the acid is present it will fume with the moisture in the breath.

The second test is applied by shaking the compound with a dilute, cold, neutral solution of potassium permanganate. If an unsaturated compound is present oxidation takes place; the color of the solution disappears and brown manganese dioxide is formed.

The tests which have been described are used to detect unsaturated compounds. It is difficult to prove that a compound under study is a hydrocarbon. To do this a qualitative test for elements other than carbon, hydrogen, and oxygen must be made. If such elements are shown to be absent, the substance must be tested for the characteristic groups which contain oxygen. These tests will be developed in the pages to follow. If all such tests yield negative results the conclusion can be drawn that the substance studied belongs to the class of unsaturated hydrocarbons.

36. Heat of Combustion and Heat of Formation of the Hydrocarbons of the Ethylene Series. — The significance of the heat of combustion and heat of formation of the members of the ethylene series can best be seen by comparing the values of the constants of these hydrocarbons with those of the paraffins.

	Heat of Combustion	Heat of Formation
Ethane	372.3 Cal.	23.3 Cal.
Ethylene	341.1 "	−14.6 "
Propane	528.4 "	30.5 "
Propylene	499.3 "	− 9.4 "
Butane	687.2 "	35.0 "
Butylene	650.2 "	− 2.6 "

The heat of formation of ethane is 23.3 Cal. This means that when 24 grams of carbon and 6 grams of hydrogen unite to form ethane, 23.3 calories of heat are evolved — the reaction is exothermic — and, consequently, ethane contains less chemical energy than the carbon and hydrogen from which it was formed. On the other hand, ethylene is an endothermic compound. In order to transform 24 grams of carbon and 4 grams of hydrogen into ethylene, the energy equivalent to 14.6 calories is necessary. This means that ethylene contains more chemical energy than the elements from which it was formed. As the union of the carbon and hydrogen in ethylene is attended by the absorption of heat, it is evident that the linking of the carbon atoms in the way which is indicated by the double bond, is associated with the storing up of energy. Unsaturated compounds are, therefore, more active than saturated compounds.

PROBLEMS

1. Write equations for the general reactions by which hydrocarbons of the ethylene series may be prepared.

2. Write equations for reactions which illustrate the chemical properties of the olefines.

3. Starting with methyl alcohol and inorganic reagents prepare (*a*) C_2H_4, (*b*) $CH_3CH{=}CH_2$, (*c*) $(CH_3)_2C{=}CH_2$.

4. How could you detect the presence of unsaturated hydrocarbons in a sample of gasoline?

5. How could you determine the volumetric composition of mixtures known to consist of (*a*) methane and ethylene, and (*b*) ethane, ethylene, and air?

6. Write the graphic formulas of the compounds formed by action of (*a*) sulphuric acid on unsymmetrical diethylethylene, (*b*) bromine on symmetrical dipropylethylene, and (*c*) hydriodic acid on *n*-butylene.

7. Write the graphic formulas and name the hydrocarbons of the composition C_5H_{10}.

CHAPTER IV

HYDROCARBONS OF THE ACETYLENE SERIES. DIOLEFINES

37. An homologous series of hydrocarbons is known the members of which show a higher state of unsaturation than that of the olefines. Acetylene, the most important member of the series, has the composition indicated by the formula, C_2H_2. It contains two less hydrogen atoms than ethylene. We have seen in the study of the relation between ethylene and ethane that the removal of hydrogen atoms from compounds leads to the formation of substances which are active chemically. This activity, called unsaturation, shows itself in the ability of such substances to form new compounds as the result of direct addition to other elements. The relation between the composition of ethylene and acetylene, C_2H_4 and C_2H_2, is an indication that acetylene is more highly unsaturated than ethylene — that is, that it possesses the ability to add more atoms than does ethylene. The facts are in accord with this conclusion. Whereas one molecule of ethylene unites with two atoms of bromine, one of acetylene can unite with four atoms of the halogen. In both cases a saturated compound is formed, which is a substitution-product of ethane, C_2H_6.

The hydrocarbons of this series should be studied in the light of their relation to the olefines. The methods of preparation are analogous to those explained when ethylene was considered, but the extent of the elimination of halogen atoms or of halogen hydride must be increased; four halogen atoms or two molecules of the hydride must be removed. The reactions of acetylene and its homologues are, in general, analogous to those of ethylene.

The graphic formula of acetylene which is used to represent the structure of its molecule and to indicate that it is capable of adding to itself four univalent atoms is $HC \equiv CH$. In such addition, two of the three bonds which are represented as holding the carbon atoms together are said to break. This leaves one bond between the carbon atoms. The two latent affinities of each of these atoms come into play, and, as a consequence, four atoms are added to the molecule.

The hydrocarbons in this series are usually named as substitution-products of acetylene; for example, methyl-acetylene, dimethyl-acetylene, etc. In another system of nomenclature the name of any hydrocarbon is derived from that of the saturated hydrocarbon which contains the same number of carbon atoms, by replacing the termination *ane* by *ine;* thus, acetylene, C_2H_2, is called ethine, and methyl-acetylene, $CH_3C{\equiv}CH$, propine. Some of the hydrocarbons have, in addition, names which were given them when they were first prepared. Propine is often called, for example, allylene.

38. Acetylene, C_2H_2. — This hydrocarbon is the most important in the series on account of the fact that it illustrates in its reactions the chemical conduct of its homologues, and because it is used extensively as an illuminant.

Acetylene is a gas which has a garlic-like odor. It is slightly soluble in most liquids: one volume of water, benzene, and alcohol dissolve one, four, and six volumes, respectively, of the hydrocarbon. A solution of acetylene in acetone is used as a convenient source of the gas for lighting purposes. One volume of acetone dissolves at the ordinary temperature and pressure 25 volumes, and at pressure of 12 atmospheres 300 volumes of acetylene.

Under a pressure of 48 atmospheres at 1° acetylene condenses to a colorless liquid which has the specific gravity 0.45 and boils at $-84°$.

The most important application of acetylene is its use as an illuminant. The high illuminating power of an acetylene flame is due to the fact that the gas contains a large percentage of carbon, and that when it burns the large amount of heat produced raises the temperature of the flame to a high point.

Acetylene is formed when hydrogen is heated with carbon at the temperature of the electric arc, and when most hydrocarbons are decomposed at a high temperature. It is also formed when certain complex organic substances are subjected to destructive distillation at a high temperature. Coal-gas contains about

.08 per cent of acetylene, which is formed in this way. Incomplete combustion of hydrocarbons and other organic compounds leads to the formation of the gas. Acetylene is formed in small quantity when a Bunsen burner strikes back and the gas burns at the base in a supply of air which is not sufficient for complete combustion. The odor of the gases formed is not that of pure acetylene, but of other substances present.

Acetylene is most conveniently prepared by the action of water on calcium carbide. When lime and coal are heated in an electric furnace the oxide is reduced, and at the high temperature the metal unites with carbon and calcium carbide results. The reaction takes place according to the equation,

$$CaO + 3\,C = CaC_2 + CO$$

Calcium carbide is a hard, white, crystalline substance when pure; the brown color of the commercial material is due to the presence of iron and other impurities. A steady stream of acetylene can be produced by allowing water to fall, drop by drop, on the carbide. The equation for the reaction is,

$$CaC_2 + 2\,H_2O = Ca(OH)_2 + C_2H_2$$

In some forms of generators for the gas, which are used commercially, the finely powdered carbide runs slowly into a reservoir of water. A better regulation of the gas supply is effected by using this method. Acetylene prepared from commercial calcium carbide usually contains hydrogen sulphide and phosphine. These substances may be removed by passing the gas through a solution of mercuric chloride in hydrochloric acid.

39. Acetylene can be prepared by other methods which are analogous to those used to prepare ethylene. While these methods lack practical value in the case of this hydrocarbon, which can be so readily prepared from calcium carbide, they are of importance since similar methods must be used to prepare the homologues of acetylene. Moreover, compounds other than hydrocarbons may contain carbon atoms held together in the way in which these atoms are united in acetylene, and the methods about to be described can be used to prepare such compounds.

The most important general method of preparing a compound containing a triple bond is to heat a saturated halogen derivative which contains two halogen atoms joined either to the same or adjacent carbon atoms, with an alcoholic solution of potassium hydroxide. Acetylene may be prepared in this way from ethylene bromide: —

$$BrH_2C-CH_2Br + 2\ KOH = HC\equiv CH + 2\ KBr + 2\ H_2O$$

The removal of four halogen atoms from a saturated compound by means of a metal also leads to the establishment of a triple bond. When an alcoholic solution of symmetrical tetrabromethane is warmed with zinc, acetylene is formed: —

$$Br_2HC-CHBr_2 + 2\ Zn = HC\equiv CH + 2\ ZnBr_2$$

40. Acetylene and other substances which contain two carbon atoms joined by a triple bond, show in their chemical behavior a high state of unsaturation. Acetylene does not react with chlorine in the dark, but in diffused daylight addition of the halogen takes place, and a dichloride, $C_2H_2Cl_2$, and a tetrachloride, $C_2H_2Cl_4$, are formed. If the acetylene has not been carefully purified, the reaction often takes place with explosive violence and carbon and hydrogen chloride are formed. When the gas is passed into bromine the chief product of the reaction is acetylene tetrabromide: —

$$HC\equiv CH + 2\ Br_2 = Br_2HC-CHBr_2$$

Acetylene reacts with iodine which has been covered with alcohol, and forms a diodide, $C_2H_2I_2$. Acetylene does not appear to unite directly with hydrochloric acid; with concentrated hydrobromic acid at 100° a reaction takes place slowly, and one molecule of the hydrocarbon and one of the halogen acid unite and form bromethylene, $H_2C=CHBr$. Under similar conditions with hydriodic acid, iodo-ethylene, $H_2C=CHI$, and ethylidene iodide, CH_3CHI_2, are formed. Acetylene and hydrogen unite in the presence of finely-divided platinum to form ethane.

Acetylene, like other unsaturated compounds, is readily oxidized by a solution of potassium permanganate. Oxalic acid, carbon dioxide, and other substances are formed as the result of the oxidation.

Mixtures of acetylene and air explode with great violence. The proportion of acetylene in such mixtures can vary between wide limits, namely, from 3 to 82 per cent by volume. In the case of methane and ethylene, the limiting volumes of explosive mixtures are 5 and 13 per cent and 4 and 22 per cent, respectively.

Acetylene polymerizes when it is passed through a tube heated to dull redness. Among the compounds formed is benzene, C_6H_6, which is produced as the result of the union of three molecules of the unsaturated hydrocarbon.

The reactions of acetylene which have been mentioned are analogous to those of the unsaturated hydrocarbons containing a double bond. Acetylene and other compounds which contain a carbon atom in combination with hydrogen and joined to a second atom in the manner which is represented by a triple bond, that is, those containing the group $H-C\equiv$, show characteristic properties which serve to distinguish them from other substances. Such compounds are converted into metallic derivatives when they are treated with an ammoniacal solution of cuprous chloride or of silver chloride. If acetylene is passed into a solution of cuprous chloride in ammonia, a red precipitate is formed which has the composition C_2Cu_2. This compound, which is a carbide of copper, is usually called copper acetylide. It explodes, when dry, if it is struck or heated to 100°-120°. When treated with hydrochloric acid or with a solution of potassium cyanide, acetylene is formed.

Acetylene and other compounds which contain the $\equiv CH$ group react with sodium and potassium and form metallic derivatives. When acetylene is passed over gently-heated sodium one-half of the hydrogen in the hydrocarbon is replaced by the metal and a sodium acetylide, C_2HNa, is formed. At red heat the disubstituted-product C_2Na_2 results.

41. Structure of Acetylene. — The structural formula of acetylene is deduced from its reactions. Arguments similar to those used in the case of ethylene and propylene lead to the conclusion that the state of unsaturation is brought about as the result of the relation existing between the two carbon atoms in the hydrocarbon. The formula is written, accordingly, $HC\equiv CH$. The fact that acetylene is formed when iodoform, CHI_3, is treated with zinc is an argument in favor of the accepted structure of the hydrocarbon. Recent work on substitution-products of acetylene has led to the view that derivatives of a hydrocarbon isomeric with acetylene and having the structure $H_2C=C$ may exist.

A study of the heat of combustion of acetylene throws some light on the nature of the union of the carbon atoms in the compound, and on its chemical activity and instability. When one gram-molecule of acetylene (26 grams) burns in oxygen, 313.8 Cal. are set free. The heat produced when the same amount of carbon (24 grams) and hydrogen (2 grams) in the free state are burned is 262.3 Cal. Acetylene is, accordingly, an endothermic compound; its heat of formation is -51.5 Cal. This storing-up of energy in the molecule leads to the instability and reactivity which is characteristic of acetylene and similar compounds. Acetylene can not be safely stored when under a pressure greater than two atmospheres, or when liquified. Under these conditions the substance may explode as the result of a shock.

HIGHER MEMBERS OF THE ACETYLENE SERIES

42. A number of hydrocarbons of this series, the general formula of which is C_nH_{2n-2}, have been prepared by the application of the general methods of synthesizing compounds containing carbon atoms joined by a triple bond. In general, these hydrocarbons resemble acetylene in chemical properties. Only those, however, which contain the $\equiv CH$ group form metallic compounds. Methylacetylene (propine), $CH_3C\equiv CH$, which is usually called allylene, is a gas; ethylacetylene (butine), $CH_3CH_2.C\equiv CH$, boils at 18°. As is the case in other homologous series, increase in the number of carbon atoms is accompanied by an increase in boiling-point. The higher members of the series are solids.

43. Identification of Compounds Containing a Triple Bond.—The unsaturated character of compounds which contain carbon atoms joined by a triple bond is shown by their behavior with bromine and with a solution of potassium permanganate. Tests for such compounds are carried out in the manner described under ethylene (**35**). Acetylene derivatives can be readily distinguished from compounds containing doubly linked carbon atoms, only when the former contain the group $\equiv CH$. In the case of such substances an insoluble colored copper derivative is formed when the compound is treated with an ammoniacal solution of cuprous chloride. There is no simple qualitative test which serves to distinguish a compound of the structure $RC \equiv CR$ (R is used to represent a radical) from one of the structure $R_2C = CR_2$.

DIOLEFINES

44. A number of hydrocarbons are known which are isomeric with members of the acetylene series, but do not contain a triple bond. They contain four less hydrogen atoms than the saturated hydrocarbon with the same number of carbon atoms. A study of the reactions of these hydrocarbons has shown that the property of unsaturation which they possess is produced as the result of the presence of two double bonds. *Allene*, which is isomeric with allylene, has the structure represented by the formula $H_2C = C = CH_2$. The hydrocarbons of this series are called *diolefines* on account of the fact that they contain two double bonds. Allene is sometimes called propadiene. The first two syllables indicate that the compound contains three carbon atoms (from propane C_3H_8); the termination *diene* indicates the presence of two double bonds in the compound. Other compounds are named in a similar way. The methods of preparation and reactions of the members of this series are analogous to those of the hydrocarbons of the ethylene series.

45. Isoprene, $C_5H_{10}^{\,8}$ is a diolefine of particular interest on account of the fact that it is converted into India rubber when it is treated with concentrated hydrochloric acid. The hydrocarbon is a liquid which boils at 37°. It is formed as the result of the destructive distillation of India rubber, or when turpentine is passed through a red hot tube. The reactions of the substance indicate that it has the structure

$$\begin{array}{l} CH_2 = \underset{\displaystyle CH_3}{\underset{|}{C}} - CH = CH_2 \end{array}$$

Like other olefines it can be readily polymerized. When isoprene undergoes this change there are formed liquid hydrocarbons, called terpenes, on account of their relation to turpentine, and a substance which appears to be identical with rubber. The synthesis of rubber on the commercial scale is a problem in organic chemistry which has not been solved.

PROBLEMS

1. Write equations for the general reactions by which the hydrocarbons of the acetylene series may be prepared.

2. Write equations for reactions which illustrate the chemical properties of compounds which contain a triple bond.

3. State how you could distinguish from one another (*a*) propane, propene, and propine, (*b*) methyl-acetylene and dimethyl-acetylene, (*c*) allene and allylene.

4. Write reactions by which the following may be prepared, (*a*) acetylene, (*b*) propine, (*c*) dimethyl-acetylene, (*d*) methyl-ethyl-acetylene.

CHAPTER V

MONATOMIC SATURATED ALCOHOLS

46. The derivatives of the hydrocarbons which contain oxygen are of the greatest importance, as most organic compounds that occur in nature contain this element. The great variety in chemical properties shown by these substances results from the relation which the oxygen atoms present bear to the other atoms in the molecule. A study of many of these compounds has shown that they can be brought into a comparatively small number of groups, the members of which show similar chemical properties. The substances known as alcohols constitute one of these groups. From the hydrocarbons CH_4, C_2H_6, C_3H_8, etc., can be prepared alcohols which have the composition CH_4O, C_2H_6O, C_3H_8O, etc., respectively. The chemical properties of these compounds lead to the conclusion that they are hydroxyl derivatives of the hydrocarbons. Alcohols are known which contain more than one hydroxyl group. Those containing one such group are called monatomic alcohols. The polyatomic alcohols are classified as diatomic, triatomic, etc.

47. Methyl Alcohol, CH_3OH. — Compounds occur in certain plants from which methyl alcohol can be easily obtained in small quantities. When methyl salicylate (oil of wintergreen), which is present in checkerberries, is heated with a solution of sodium hydroxide, methyl alcohol and the sodium salt of salicylic acid are obtained. The alcohol is formed, along with other substances, when wood is subjected to destructive distillation. This method is used in the industrial preparation of methyl alcohol, which is commercially known as wood-spirit.

The process is carried out by heating wood out of contact with air in retorts which are so arranged that the volatile products formed can be condensed.

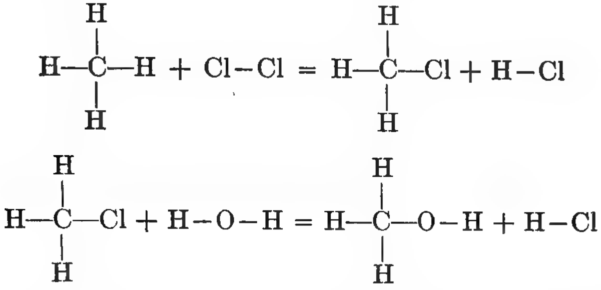
When wood is heated decomposition begins at about 160°. Between this temperature and 275° a watery distillate, called *pyroligneous acid,* is formed. As the temperature is increased, methane, ethane, ethylene, carbon monoxide, and carbon dioxide are given off along with liquid and solid hydrocarbons. At about 450° the decomposition is complete, and a residue of charcoal remains. The yield of the products of distillation is affected by the kind of wood used. That from birch, beech, and oak trees produces the largest amount of pyroligneous acid, — about 30 per cent of the weight of the wood. The crude acid contains acetic acid, acetone, and water together with a number of other substances which are present in small amounts.

Methyl alcohol is obtained by first neutralizing the crude acid with milk of lime, which forms calcium acetate with the acetic acid present, and then submitting the liquid to fractional distillation. A second distillation from quicklime yields an alcohol of 99 per cent. The alcohol so obtained contains acetone and other substances in small quantities, from which it can not be separated by distillation, and which impart to it an unpleasant odor. Pure methyl alcohol can be prepared from the commercial wood-spirit in a number of ways. In one of these the impure alcohol is treated with anhydrous calcium chloride, which forms with the alcohol a crystalline compound having the formula $CaCl_2.4CH_3OH$. This substance is first heated to 100°, a temperature at which the acetone and other volatile impurities are vaporized; then, after treatment with water, the alcohol is distilled off.

Methyl alcohol is used commercially as a solvent for shellac, in making varnish, in the preparation of aniline dyes and formaldehyde, and for other purposes. Crude wood-spirit is used in large quantities in the preparation of "denatured" alcohol. This use is based on the fact that the crude spirit has a disagreeable odor and is poisonous and, accordingly, renders the grain alcohol unfit to drink.

Methyl alcohol is a colorless liquid which boils at 66° and freezes at $-93.9°$. It mixes with water in all proportions, and is a good solvent. Many substances which are soluble in water and insoluble in most organic liquids dissolve in methyl alcohol. It burns with a pale blue flame, which does not deposit soot, and can be conveniently used as a source of heat.

48. Methyl alcohol can be prepared from methane by a method that leads to a definite conception of its structure. When the hydrocarbon is treated with chlorine, methyl chloride is formed. This is converted into methyl alcohol by the action of water at a high temperature. The simplest explanation of the reactions is that indicated by the equations: —



$$\mathrm{H{-}\overset{\displaystyle H}{\underset{\displaystyle H}{C}}{-}H + Cl{-}Cl = H{-}\overset{\displaystyle H}{\underset{\displaystyle H}{C}}{-}Cl + H{-}Cl}$$

$$\mathrm{H{-}\overset{\displaystyle H}{\underset{\displaystyle H}{C}}{-}Cl + H{-}O{-}H = H{-}\overset{\displaystyle H}{\underset{\displaystyle H}{C}}{-}O{-}H + H{-}Cl}$$

The replacement of a halogen atom in a compound by a hydroxyl group is an important method of preparing alcohols. As iodides react with water more readily and at a lower temperature than chlorides, they are more frequently used. In order to increase the rate at which the alcohol is formed the alkyl iodide is shaken or heated with water and silver oxide. It is probable that a reaction takes place between the iodide and the silver hydroxide which is formed from the oxide and passes into solution. The equation is as follows: —

$$\mathrm{CH_3I + AgOH = CH_3.OH + AgI}$$

The slowness with which the reaction proceeds is in marked contrast with the instantaneous precipitation of silver iodide in a reaction between substances that are ionized to a high degree.

49. Chemical Properties of Methyl Alcohol. — Methyl alcohol reacts with a number of different kinds of compounds on account of the fact that it contains a hydroxyl group. The more important reactions of the substance will be described at some length, as similar reactions are shown by other alcohols, and are typical.

Methyl alcohol may be considered as a compound formed by the replacement of a hydrogen atom in methane by a hydroxyl group, or as water in which one hydrogen atom is replaced by the methyl radical. A consideration of the substance from these points of view will be helpful in understanding and remembering the reactions to be described.

Methyl alcohol reacts with many substances with which water reacts. It forms molecular compounds with certain anhydrous salts, which are analogous to hydrated salts. For example, the following compounds are known: $MgCl_2.6CH_3OH$ and $MgCl_2.6H_2O$; $CuSO_4.2CH_3OH$ and $CuSO_4.5H_2O$.

Sodium and potassium readily replace a part of the hydrogen in both water and methyl alcohol. The reactions in the two cases are analogous: —

$$2\ HOH + 2\ Na = 2\ HONa + H_2$$
$$2\ CH_3OH + 2\ Na = 2\ CH_3ONa + H_2$$

In the reaction with the alcohol but one-fourth of the hydrogen — that in the hydroxyl group — is replaced. The reaction takes place when sodium is put into the cold alcohol. Heat is liberated and hydrogen is rapidly evolved. The substance formed is called sodium methylate, or sodium methoxide. It is a white solid which is decomposed by water according to the equation,

$$CH_3ONa + HOH = CH_3OH + NaOH$$

It is a reactive substance and is used in the preparation of many compounds.

It will be remembered that water decomposes the halogen compounds of acid-forming elements. For example, phosphorus trichloride and water react according to the equation,

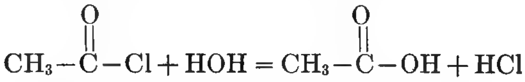
$$PCl_3 + 3\ HOH = P(OH)_3 + 3\ HCl$$

Methyl alcohol shows its relation to water by entering into an analogous reaction: —

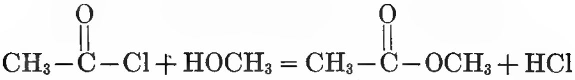
$$PCl_3 + 3\ CH_3OH = P(OH)_3 + 3\ CH_3Cl$$

This reaction, which takes place readily, serves as a convenient means of preparing the alkyl chlorides. Methyl alcohol is converted into methyl bromide and methyl iodide by the bromide and iodide of phosphorus.

There is a class of organic compounds known as acyl chlorides which react readily with alcohols. As the compounds formed are of interest and value, and as the reaction is often used to test substances for the presence of an alcoholic hydroxyl group, it is of importance. An acyl chloride is formed from an acid by the replacement of the hydroxyl group, which it contains, by chlorine. Phosphorus trichloride, PCl_3, is the chloride of phosphorous acid, $P(OH)_3$, and sulphuryl chloride, SO_2Cl_2, is the chloride of sulphuric acid, $SO_2(OH)_2$. The formula of acetic acid has already been given as $CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-OH$. Acetyl chloride has the formula $CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-Cl$. Acetyl chloride reacts with water to form acetic acid and hydrochloric acid, and with methyl alcohol to form methyl acetate and hydrochloric acid. The equations for the reactions are as follows: —

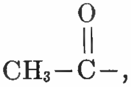
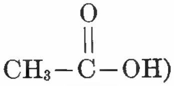


$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-Cl + HOH = CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-OH + HCl$$



$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-Cl + HOCH_3 = CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-OCH_3 + HCl$$

When acetyl chloride is added to methyl alcohol, the temperature rises and a copious evolution of hydrogen chloride takes place. Other alcohols show a similar reaction.

The replacement of a hydrogen atom in water by a methyl group results in the formation of a compound which shows some of the properties of a base. Water is the type of neutrality. If half the hydrogen in water is replaced by an element, the resulting compound may be an acid or a base. The nature of the element determines the properties of the compound formed; thus, we have ClOH and $P(OH)_3$, and NaOH and $Fe(OH)_3$. Chlorine and phosphorus form hypochlorous and phosphorous acids, respectively, while the hydroxides of the metallic elements are bases. In organic chemistry the properties of the compounds formed by the replacement of a hydrogen atom in water by radicals are determined, in an analogous way, by the nature of the radical present. Thus, as we shall see, the replacement of hydrogen in water by alkyl radicals (methyl, ethyl, etc.) results in the formation of substances which show properties analogous to some of those of bases, whereas the replacement by the radicals present in acids, such as acetyl  $CH_3-\overset{O}{\overset{\|}{C}}-$, leads to the formation of acids (acetic acid  $CH_3-\overset{O}{\overset{\|}{C}}-OH$).

The alcohols show their basic character by reacting with acids to form water and substances which show some resemblance to salts. These compounds are known as ethereal salts or esters. The alcohols are, however, neutral to litmus, as they are not appreciably ionized.

Methyl alcohol reacts with hydrochloric acid when the two are heated in a sealed tube. The reaction takes place according to the equation,

$$CH_3OH + HCl = CH_3Cl + H_2O$$

This reaction does not take place when the alcohol and the concentrated hydrochloric acid are mixed, or even distilled together. In the presence of anhydrous zinc chloride, which serves as a dehydrating agent, gaseous hydrogen chloride reacts with warm methyl alcohol according to the equation given above. Methyl alcohol does react, however, with strong aqueous solutions of hydrobromic acid and hydriodic acid. Methyl bromide and methyl iodide may be conveniently prepared by distilling a mixture of the alcohol and a concentrated solution of the halogen acid. In order to convert a large proportion of the alcohol into bromide or iodide, it is necessary to have present an excess of the halogen acid as the reactions are reversible: —

$$CH_3OH + HI = CH_3I + H_2O$$

The fact that methyl alcohol is much more readily converted into methyl iodide by hydriodic acid than into methyl chloride by hydrochloric acid, is evidence that the reactions involved are probably not of the same nature as those of neutralization in inorganic chemistry. It is probable that the reaction between the alcohol and the halogen acid involves the formation of an intermediate addition-product, which subsequently decomposes into water and the alkyl halide. That such addition-products can exist is shown by the fact that when methyl alcohol is treated with liquid hydrobromic acid, a compound having the composition $CH_3OH.HBr$ is formed.

When methyl alcohol is warmed with concentrated sulphuric acid, acid methyl sulphate, usually called methyl sulphuric acid, is formed:—

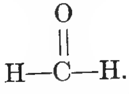
$$CH_3OH + H_2SO_4 = CH_3.H.SO_4 + H_2O$$

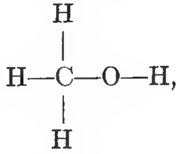
If the alcohol is distilled with the acid, dimethyl sulphate $(CH_3)_2SO_4$, results. Methyl nitrate can also be prepared by distilling the alcohol with nitric acid.

Methyl alcohol reacts slowly with organic acids. When equal molecular quantities of the alcohol and an acid are mixed, complete reaction does not take place, as the compound formed is decomposed by water, the reaction being reversible. For example, methyl alcohol and acetic acid form methyl acetate and water:—

$$CH_3COO.H + CH_3OH = CH_3COO.CH_3 + H_2O$$

When the two substances are heated in a sealed tube at 150°-155° in order to increase the rate of reaction, 56 per cent of the alcohol and acid are converted into methyl acetate. The significance of this fact will be discussed more fully later (**128**). In order to complete the reaction it is necessary to add to the mixture a dehydrating agent. When sulphuric acid is used, reaction takes place when the substances are gently heated.

50. Alcohols differ from hydrocarbons in the ease with which they are oxidized. When an aqueous solution of methyl alcohol is warmed with an oxidizing agent, such as potassium permanganate or chromic acid, oxidation takes place. The final products are carbon dioxide and water. By careful regulation of the process, oxidation-products intermediate between the alcohol and carbon dioxide may be obtained. When a red hot spiral of copper wire which has been superficially oxidized, is put into a dilute solution of methyl alcohol in water, a part of the alcohol is oxidized to formaldehyde,  $\mathrm{H{-}\overset{\overset{O}{\|}}{C}{-}H}$. This compound (**142**) has a marked odor, and enters into a number of characteristic reactions with other substances which serve as a means of detecting its presence. These reactions will be described when the aldehyde is considered. The formation of formaldehyde in this way is used as a *test for methyl alcohol.*

51. Structure of Methyl Alcohol. — A study of the reactions of methyl alcohol which have been described, leads to the conclusion that the compound contains a hydroxyl group. Its preparation from methyl chloride by the action of water leads to the same conclusion, and furnishes evidence that the substance contains a methyl group. Further, the structure arrived at, which is expressed by the graphic formula  $H-\overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}}-O-H$, is the only one possible if we accept the view that the valence of carbon, oxygen, and hydrogen are four, two, and one, respectively. This view of the structure is in accord with the fact that one hydrogen atom differs from the other three in its relation to the molecule. It will be remembered that but one-fourth of the hydrogen in methyl alcohol can be replaced by sodium. No reactions of methyl alcohol are known which can not be interpreted by the use of the formula given, if we except the so-called molecular compounds which the alcohol forms with salts, such as the compound $CaCl_2.4CH_3OH$. These, however, are no doubt similar in structure to hydrated salts such as $CaCl_2.6H_2O$, which our present valence theories do not adequately explain. It is possible that under certain conditions oxygen may have a valence of four, and that the additional power of combination which the oxygen atom possesses makes it possible for such molecular compounds to exist.

52. Ethyl Alcohol, C_2H_5OH. — This substance, which is often called grain alcohol, or alcohol, has been known from the earliest times, as it occurs in wine formed as the result of fermentation of grape juice. It is present in the fruit and juices of certain living plants. Alcohol is made in large quantities, not only in the preparation of alcoholic beverages, but for industrial purposes as it has extensive applications in the arts. Alcohol is formed as the result of the fermentation of sugars. In addition to the sugar which is present in sugar-cane and in beets, substances are found in fruits and vegetables which are sweet, and which readily undergo fermentation. These are called sugars. One of these is dextrose and has the formula $C_6H_{12}O_6$. On account of the fact that this sugar occurs abundantly in grapes, it is often called grape sugar. The formation of wine from grape juice is the result of the fermentation of the dextrose which the juice contains. In the technical preparation of alcohol, either starch is first converted into a sugar, called maltose, which is then fermented, or molasses, which contains sugars, is used.

In the United States alcohol is usually prepared from the starch contained in corn, rye, or barley; in England rice is also used, while in Germany the potato and molasses furnish the substances from which alcohol is made. The grain used is ground to a coarse meal, mixed with water, and heated for an hour or two with steam under a pressure of two or three atmospheres. This treatment serves to burst the outer coating which surrounds the starch granules. The mixture is then cooled to 63° and ground malt, which contains the ferment known as diastase, is added. Malt is usually prepared by allowing barley, which has been softened by water, to sprout in a warm moist atmosphere. During the germination of the grain diastase is formed.

When malt is added to the warm mixture of starch and water, the conversion of the starch into maltose rapidly takes place. In about an hour, when this change is complete, the solution is cooled and diluted, and yeast is added. Fermentation takes place best in a solution containing about 10 per cent of sugar, and when the temperature is kept between 20° and 25°. During the fermentation carbon dioxide is given off. The change which takes place when maltose is converted into alcohol is essentially that represented by the equation,

$$C_{12}H_{22}O_{11} + H_2O = 4\ C_2H_6O + 4\ CO_2$$

When dextrose is used the equation for the reaction is,

$$C_6H_{12}O_6 = 2\ C_2H_6O + 2\ CO_2$$

As the result of the fermentation there is obtained a mixture which contains water, alcohol, fusel oil, acids, yeast cells, and other substances. The alcohol, which is present to the extent of from 10 to 13 per cent, is separated by distillation. Very efficient rectifying apparatus is used in distilling the dilute solution of alcohol. After two distillations alcohol containing but ~~4~~ 5 per cent of water is obtained. A mixture of alcohol and water which contains 95 per cent of alcohol by weight cannot be separated into its constituents by distillation, as a mixture of this composition has a constant boiling-point below that of pure alcohol. Toward the end of the distillation there is obtained what is called fusel oil, which consists of two isomeric amyl alcohols, $C_5H_{11}OH$, together with small quantities of other alcohols.

Alcohol has been manufactured recently from saw-dust (cellulose) by converting it into dextrose (**308**) and subjecting the latter to fermentation.

53. Absolute Alcohol is the name given to alcohol from which all water has been removed. As this can not be done by distillation, 96 per cent alcohol is treated with some substance which forms a stable compound with water and which does not react with alcohol. Quicklime is generally used for this purpose. The alcohol to be freed from water is allowed to stand a day with a large amount of lime, or the two are heated together for an hour or longer. After the water has reacted with the lime to form calcium hydroxide, the alcohol is distilled off. Alcohol which contains but a small fraction of one per cent of water is obtained if the first and last parts which distill are rejected. Alcohol absolutely free from water is obtained with great difficulty, as the substance is very hygroscopic. Alcohol distilled from lime generally contains about 0.5 per cent water. This is often called "absolute" alcohol. The presence of water in alcohol can be detected by adding to it anhydrous copper sulphate; if the salt turns blue, water is present. Barium oxide dissolves in alcohol free from water and imparts to it a yellow color; if water is present, the oxide does not dissolve.

Pure alcohol is a colorless mobile liquid which has a characteristic odor. It boils at 78.3°, solidifies at $-112°$, and has the specific gravity of 0.7936 at $\frac{15°}{4°}$. It is miscible in all proportions with water, the mixing being accompanied with contraction and rise in temperature. The greatest contraction takes place when 48 volumes of water and 52 volumes of alcohol are mixed. The volume of the mixture when measured at 20° is 96.3 instead of 100. Alcohol can be obtained readily from a moderately dilute aqueous solution by saturating the solution with potassium carbonate. The alcohol which separates contains about 9 per cent of water.

54. Alcoholic Beverages. — Alcoholic beverages may be divided into two classes, — those which have been distilled and contain a high percentage of alcohol, and those which are the direct product of fermentation. To the first class belong whisky, brandy, gin, rum, and liqueurs, and to the second, wine, champagne, and beer.

Whisky is prepared from fermented grain. The malt which is used, is dried over an open fire, and, consequently, acquires a characteristic flavor, which is transmitted to the whisky. After fermentation, the product is distilled from a still of copper, and the distillate condensed in a worm. Redistillation yields a spirit which is diluted with enough water to make a solution which contains 50 to 58 per cent alcohol. The quantity of alcohol is usually stated in the United States in the per cent alcohol by *volume*, as taxes are levied on that basis. The percentages given here refer to the volume standard. The crude whisky is stored in barrels of wood and allowed to age until the flavor of the fusel oil disappears.

Brandy is made by distilling wine or the fermented juices of apples, peaches, or other fruits. It contains from 44 to 55 per cent of alcohol. Cognac is a high grade of brandy made from wine.

Gin, which contains about 40 per cent of alcohol, is made from grain. The characteristic taste and odor are produced as the result of the final distillation, which is made with juniper berries, anise seed, or other aromatic substances, in the still.

Rum is made from fermented molasses. It contains from 45 to 55 per cent alcohol. The flavor of rum is largely due to the ethyl butyrate and ethyl formate which it contains.

Liqueurs and *Cordials* are usually prepared by mixing alcohol and water with various flavoring essences.

Beer is an undistilled beverage which is prepared by fermenting malted grain. Hops are added to give to the beer a bitter taste. It contains from 3 to 5 per cent of alcohol.

Wine and *Champagne* are fruit juices which have undergone alcoholic fermentation produced by a ferment present in the grapes and in the air of grape-producing regions. The sugars which yield the alcohol are chiefly dextrose and levulose. Wine must be kept for some years before it acquires a pleasant odor and taste. During this time tannin and other substances are precipitated and a part of the fusel oil and acids present react to form ethereal salts which give to the wine its characteristic odor. Wines vary greatly in the percentage of alcohol which they contain. Claret, Rhine wines, and sauternes contain from 7 to 10 per cent; port, sherry, and madeira from 12 to 20 per cent. The last-named wines are often "fortified" by adding alcohol to them, as a wine prepared by fermentation can not contain more than 18 per cent alcohol.

In the preparation of champagne the fermentation is allowed to take place in bottles which are corked. In this way the carbon dioxide formed is retained in the wine. The bottles are placed with the cork down and are frequently turned so that the sediment collects in the neck. When fermentation ceases the bottles are opened for an instant, when the sediment is blown out. A small amount of a liqueur is added, and the cork is inserted and wired on. Champagne contains from 8 to 11 per cent alcohol.

55. Analysis of Alcoholic Beverages. — The amount of alcohol in a solution is determined as follows: A mixture of 200 cc. of the sample and 100 cc. of water is distilled until 200 cc. have been collected. From the specific gravity and temperature of the distillate the percentage of alcohol can be ascertained by reference to tables in which the specific gravities of aqueous solutions of alcohol are tabulated.

The tax levied on alcohol in the United States is $1.10 per gallon of proof spirit, which contains 50 per cent of alcohol by volume. Alcohol rendered unfit to drink by the addition of wood alcohol, benzene, or other substances prescribed by law, is called *denatured alcohol.* It is exempt from taxation.

Alcoholic beverages contain many substances in small quantities which affect markedly their quality and value. There are present in wines, for example, in addition to alcohol, acids which are volatile with steam, acids which are not volatile, glycerin, tannin, sugars, esters, solids which are converted into an ash when ignited, etc. The quantitative determination of such substances is often valuable in helping to decide upon the genuineness and value of a wine. The details of these processes and the interpretation of the results are considered in books on the analysis of foods.

56. Uses of Ethyl Alcohol. — Ethyl alcohol is used in pharmacy as a solvent in the preparation of tinctures, essences, and extracts, and in the manufacture of iodoform, chloroform, ether, chloral, and other compounds. It is used to preserve biological specimens, as alcohol coagulates albumen and arrests the growth of the organisms which bring about putrefaction. Alcohol is used in large quantities as a solvent in varnish making, and in other industries in which shellac is used, *e.g.*, the manufacture of felt hats. It is also used in the manufacture of dyes, vinegar, perfumery, collodion, and many other things of commercial value.

Alcohol burns with a blue, smokeless flame, which is a convenient source of heat. Its use for heating purposes has increased since the sale of denatured alcohol was authorized.

The vapor of alcohol mixed with air forms an explosive mixture. In Europe alcohol is used successfully in gas engines to replace gasoline.

57. Chemical Properties of Ethyl Alcohol. — Ethyl alcohol resembles markedly methyl alcohol in its chemical behavior. It forms compounds with inorganic salts, such as those of the composition $CaCl_2.4C_2H_5OH$, and $PtCl_4.2C_2H_5OH$. It reacts in the cold with sodium and potassium, forming compounds in which the hydrogen in the hydroxyl group is replaced by the metal: —

$$2\ C_2H_5OH + 2\ Na = 2\ C_2H_5ONa + H_2$$

A compound of sodium ethylate and alcohol, $C_2H_5ONa.2C_2H_5OH$, crystallizes from alcohol which has been treated with sodium and then cooled. Sodium ethylate free from alcohol is obtained by heating this compound to 180°. Sodium ethylate is decomposed by water according to the equation,

$$C_2H_5ONa + H_2O = C_2H_5OH + NaOH$$

The reaction is a reversible one, as it has been shown that a solution of sodium hydroxide in alcohol reacts as if some sodium ethylate were present.

Alcohol reacts with strong inorganic acids. When warmed with concentrated sulphuric acid, ethyl sulphuric acid is formed: —

$$C_2H_5OH + H_2SO_4 = C_2H_5.SO_4H + H_2O$$

If alcohol is heated to 160°-180° with concentrated sulphuric acid, the ethyl sulphuric acid first formed is decomposed and ethylene is produced. It will be remembered that the unsaturated hydrocarbons of the ethylene series can be prepared in a similar way from other alcohols.

Ethyl bromide can be prepared conveniently by distilling a mixture of alcohol and an aqueous hydrobromic acid solution which is saturated at its boiling-point. Ethyl iodide can be prepared in a similar manner. Alcohol is not converted into ethyl chloride when it is heated with concentrated hydrochloric acid in an open vessel. In order to make the chloride, which is a gas, dry hydrogen chloride is passed into boiling alcohol which contains anhydrous zinc chloride.

Alcohol reacts with organic acids to form ethereal salts (esters), the reaction being facilitated by the presence of a dehydrating agent. For example, alcohol and acetic acid, when warmed together in the presence of sulphuric acid, form ethyl acetate: —

$$CH_3COOH + C_2H_5OH = CH_3COOC_2H_5 + H_2O$$

The hydroxyl group in alcohol can be replaced by a halogen atom by means of the halides of phosphorus. A reaction between alcohol and phosphorus trichloride takes place according to the equation,

$$3\ C_2H_5OH + PCl_3 = 3\ C_2H_5Cl + P(OH)_3$$

Other products are also formed. Under certain conditions a part of the alcohol reacts with the chloride and triethyl phosphite is formed: —

$$3\ C_2H_5OH + PCl_3 = P(OC_2H_5)_3 + 3\ HCl$$

A third reaction also takes place: —

$$C_2H_5OH + PCl_3 = POC_2H_5Cl_2 + HCl$$

No simple equation can be written to express quantitatively what happens when the alcohol and phosphorus trichloride react. By varying the conditions one or the other of the reactions given above can be made to take place to a greater or less degree. The reactions last given have been mentioned not so much on account of their importance, but because they illustrate clearly the complexity of the reactions which are met with in organic chemistry. Many reactions between inorganic substances can be represented by equations which express definitely the quantitative relations which exist between the substances entering into the reactions and those formed. In most chemical transformations in which organic compounds take part, however, a number of independent reactions take place simultaneously. When sodium bromide is prepared from sodium hydroxide and hydrobromic acid, the yield of bromide is that indicated by the equation which expresses the reaction. When ethyl bromide is prepared from ethyl alcohol and phosphorus tribromide, however, we never obtain the amount of bromide which is equivalent to the alcohol, as other reactions than that represented by the equation,

$$3\ C_2H_5OH + PBr_3 = 3\ C_2H_5Br + P(OH)_3$$

are taking place at the same time between the substances used. In the preparation of organic compounds particular attention is paid, therefore, to the conditions under which a reaction is brought about, as these conditions affect the yield of the product sought.

Alcohol reacts with the chlorides of organic acids and forms ethereal salts or esters. For example, alcohol reacts with the chloride of acetic acid (acetyl chloride) at room temperature, and ethyl acetate is formed: —

$$CH_3CO.Cl + C_2H_5OH = CH_3CO.OC_2H_5 + HCl$$

Alcohol is also converted into esters by acid anhydrides. Acetic anhydride and alcohol form ethyl acetate: —

$$(CH_3CO)_2O + C_2H_5OH = CH_3COOC_2H_5 + CH_3COOH$$

The relation between an acid and its ester, chloride, and anhydride is shown by the following formulas:—

$CH_3CO.OH$	$CH_3CO.OC_2H_5$	$CH_3CO.Cl$	$(CH_3CO)_2O$
acid	ethyl ester	acid chloride	acid anhydride

Ethyl alcohol is best identified by means of its boiling-point and that of the bromide, iodide, or benzoate (**463**) prepared from it. A convenient test for alcohol which is often used, is made by adding to a warm aqueous solution of the substance a solution of sodium carbonate and iodine; iodoform, CHI_3, precipitates as a yellow powder and can be recognized by its characteristic odor. The reactions involved will be described later (**214**). The formation of iodoform is not a positive proof of the presence of ethyl alcohol as other substances are converted into iodoform under the conditions used in the test.[1]

58. Principles of Oxidation Applied to Alcohol. — The oxidation of alcohol can be readily effected. The final products are carbon dioxide and water. By varying the conditions under which oxidation takes place, intermediate products of importance can be obtained. These reactions will be considered in some detail, as they illustrate the manner in which conclusions as to the structure of an organic compound are reached by the determination of the products formed when it is oxidized.

The first product of the oxidation of alcohol is aldehyde, which has the formula C_2H_4O. Aldehyde is converted by oxidizing agents into acetic acid. The composition of these substances is represented by the formulas,

C_2H_6O	C_2H_4O	$C_2H_4O_2$
alcohol	aldehyde	acetic acid

The first step in the oxidation involves the removal of two hydrogen atoms; the second, the addition of one oxygen atom to the aldehyde formed as the result of the first oxidation. A study of the chemical behavior of alcohol, aldehyde, and acetic acid leads to the conclusion that the structures of these substances are best represented by the formulas, —

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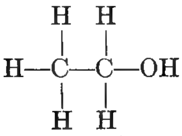
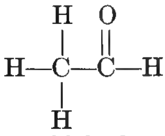
[1] Among these are aldehyde, acetone, propyl alcohol, butyl alcohol, and propionic aldehyde.



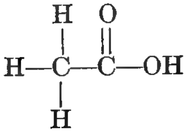
$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & — & C & — & C & — & OH \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

alcohol



$$\begin{array}{ccccccc} & & H & & O & & \\ & & | & & \| & & \\ H & — & C & — & C & — & H \\ & & | & & & & \\ & & H & & & & \end{array}$$

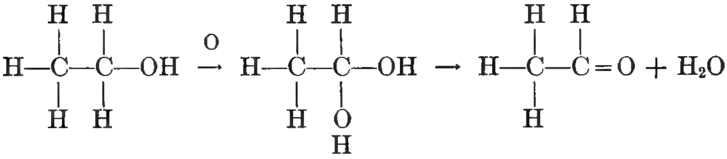
aldehyde



$$\begin{array}{ccccccc} & & H & & O & & \\ & & | & & \| & & \\ H & — & C & — & C & — & OH \\ & & | & & & & \\ & & H & & & & \end{array}$$

acetic acid

The simplest explanation of the change of alcohol into aldehyde is based on the assumption that one hydrogen atom is oxidized to a hydroxyl group, and that the resulting compound by the loss of water passes into aldehyde. The changes are illustrated by these formulas: —



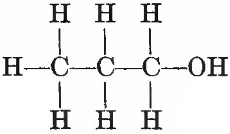
$$\begin{array}{ccccccccccccccccccc} & & H & & H & & & & & & H & & H & & & & & H & & H & & \\ & & | & & | & & & & & & | & & | & & & & & | & & | & & \\ H & — & C & — & C & — & OH & \xrightarrow{O} & H & — & C & — & C & — & OH & \rightarrow & H & — & C & — & C & =O + H_2O \\ & & | & & | & & & & & & | & & | & & & & & | & & & & \\ & & H & & H & & & & & & H & & O & & & & & H & & & & \\ & & & & & & & & & & & & H & & & & & & & & & \end{array}$$

A substance which contains the grouping of atoms represented by the graphic symbol $—\overset{\overset{\textstyle H}{|}}{C}=O$ is called an aldehyde. The conversion of aldehyde into acetic acid consists in the oxidation of a hydrogen atom to a hydroxyl group. This explanation of the course of the oxidation has been arrived at as the result of the study of the action of oxygen on many compounds. The oxidation of alcohol to aldehyde and acetic acid illustrates three important principles. First, when a compound which contains oxygen is oxidized further, the hydrogen atoms first affected are those joined to the carbon atom that is already in combination with oxygen. Second, the first step in the oxidation is to convert a hydrogen atom into a hydroxyl group. And, third, compounds which contain two hydroxyl groups linked to the same carbon atom are, in general, unstable and spontaneously form a new substance by the elimination of water.

These principles are of such importance and wide application that they should be mastered and applied to all cases of oxidation as they are described in the sequel. Like other general principles in organic chemistry they are based on the experimental study of the reactions of many substances.

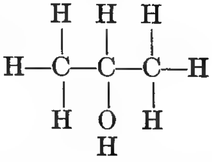
59. Propyl Alcohols, C_3H_7OH. — Two alcohols are known which have the formula C_3H_7OH. According to the structure theory, two monohydroxyl derivatives of propane are possible. These are represented by the formulas,

(1)



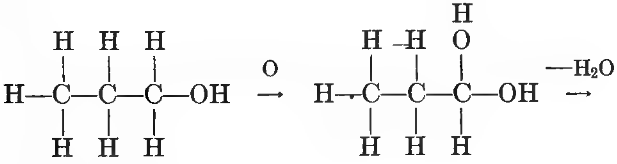
$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH$$

and (2)



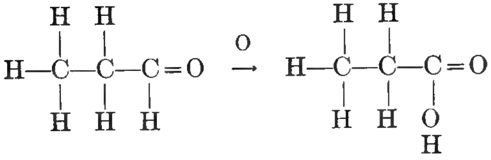
$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{H}{C}}-H$$

The properties of the two propyl alcohols lead to the conclusion that their structures should be represented by these formulas. Both compounds react with sodium, acids, halides of phosphorus, acyl chlorides, and acid anhydrides in the way which is characteristic of alcohols. A study of the products formed as the result of the oxidation of the two alcohols serves to determine the structure that should be assigned to each. The propyl alcohol which boils at 97.4° is converted by oxidizing agents into an aldehyde and an acid. It resembles ethyl alcohol in this respect. The isomeric alcohol boils at 82.1° and does not yield an aldehyde on oxidation. Acetone, a substance which belongs to the class of compounds known as ketones, is first formed. On further oxidation acetic acid is produced. These reactions can be interpreted by the application of the principles underlying the process of oxidation, which have already been given. Such an interpretation illustrates how a study of the products formed as the result of oxidation assists in the determination of the structure of organic compounds. The oxidation of the alcohol, the structure of which is represented by formula (1) above, should take place, according to the principles of oxidation, as follows: —



$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-OH \xrightarrow{O} H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{OH}{\underset{H}{C}}-OH \xrightarrow{-H_2O}$$

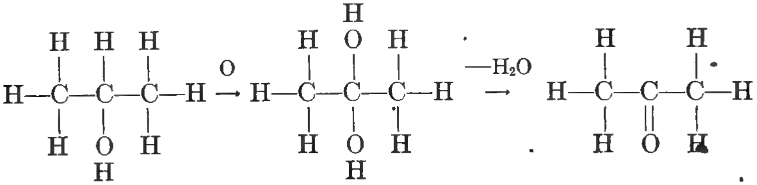
propyl alcohol



$$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{C}=O \xrightarrow{O} H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{OH}{C}=O$$

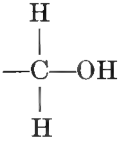
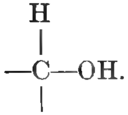
propionic aldehyde   propionic acid

The application of the same principles to the isomeric alcohol, formula (2), should yield different results: —



$$H-\underset{H}{\overset{H}{C}}-\underset{OH}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H \xrightarrow{O} H-\underset{H}{\overset{H}{C}}-\underset{OH}{\overset{OH}{C}}-\underset{H}{\overset{H}{C}}-H \xrightarrow{-H_2O} H-\underset{H}{\overset{H}{C}}-\underset{\overset{\Vert}{O}}{C}-\underset{H}{\overset{H}{C}}-H$$

isopropyl alcohol   acetone

It follows, therefore, that the alcohol which yields an aldehyde on oxidation must have the structure represented by formula (1), and the isomeric alcohol, which gives acetone, must have that represented by formula (2). The difference between the action of oxidizing agents on the two alcohols is due to the fact that one alcohol contains the group  $-\underset{H}{\overset{H}{C}}-OH$ and the other the group  $-\underset{|}{\overset{H}{C}}-OH$. In the first case two stages in the oxidation process are possible; in the second but one is possible before further oxidation leads to deep-seated decomposition of the compound in which the carbon atoms are separated. All alcohols that contain the group $-CH_2OH$ joined to a radical are called *primary alcohols;* they yield on oxidation an aldehyde and an acid containing the same number of carbon atoms as the alcohol from which it is formed. Alcohols which contain the group $=CHOH$ joined to two radicals are called *secondary* *alcohols;* they are converted by oxidizing agents into ketones which have the general formula $\begin{matrix}R\\R'\end{matrix}\!\!>C=O$, where R and R′ represent the same or different alkyl radicals. On further oxidation the ketone is converted into acids which contain a smaller number of carbon atoms than the alcohol.

n-Propyl Alcohol, $CH_3CH_2CH_2OH$, is formed in small quantities in the fermentation of sugars, and is obtained as a by-product in the manufacture of ethyl alcohol. It boils at 97.4°, mixes with water, and has the specific gravity 0.8205 at 0°. Propyl alcohol resembles ethyl alcohol in chemical properties. It is converted by oxidizing agents into propionic aldehyde and propionic acid, and has the structure $CH_3CH_2CH_2OH$. It is a *normal* primary alcohol. Alcohols which contain carbon atoms linked in a straight chain, and in which the hydroxyl group is joined to an end carbon atom, are designated by the prefix normal, which is usually abbreviated to the letter *n* in writing. Thus, the alcohol to which is assigned the formula $CH_3CH_2CH_2CH_2OH$ is called *n*-butyl alcohol.

iso-Propyl Alcohol, $(CH_3)_2CHOH$, is prepared by reducing acetone, $(CH_3)_2CO$: —

$$(CH_3)_2C:O^1 + 2H = (CH_3)_2CHOH$$

The hydrogen required is produced by the action of water on sodium amalgam, which is made by heating mercury with about 3 per cent of its weight of sodium. The amalgam so prepared is a solid and can be readily powdered. When it is treated with water the sodium present reacts slowly and hydrogen is evolved. Sodium amalgam and water are often used to reduce organic compounds. The reduction can also be accomplished by passing the vapor of acetone and hydrogen over finely divided nickel at 120°.

Isopropyl alcohol can be prepared by heating isopropyl iodide with water for a number of hours, or by boiling the iodide with lead hydroxide. Isopropyl alcohol resembles other alcohols in showing the chemical properties characteristic of compounds and contain an alcoholic hydroxyl group. Its oxidation to

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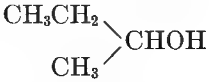
[1] A double bond is often represented by two dots, thus, C:C.

acetone shows that it is a secondary alcohol, and leads to the conclusion that its structure is represented by the formula $(CH_3)_2CHOH$. Isopropyl alcohol boils at 82.1° and has the specific gravity 0.7887 at $\frac{20°}{4°}$.

60. Butyl Alcohols, C_4H_9OH. — Four butyl alcohols are known and four are possible according to the structure theory, if we consider alcohols as hydroxyl derivatives of the hydrocarbons. The formulas of the isomeric hydroxyl substitution-products of the two butanes are as follows:

(1)	$CH_3CH_2CH_2CH_2OH$	*n*-butyl alcohol (primary)
(2)	$(CH_3)_2CHCH_2OH$	*iso*-butyl alcohol (primary)
(3)	 $\begin{matrix} CH_3CH_2 \\ CH_3 \end{matrix} > CHOH$	*sec*-butyl alcohol (secondary)
(4)	$(CH_3)_3COH$	*ter*-butyl alcohol (tertiary)

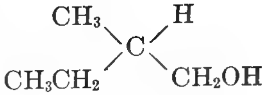
The first two formulas represent primary alcohols. Two butyl alcohols occur in fusel oil. As they are both oxidized to the corresponding aldehyde they have been assigned formulas (1) and (2). One of these alcohols can be prepared from *n*-butane. To this one is given formula (1).

sec-Butyl alcohol is prepared from methyl ethyl ketone, $\begin{matrix} CH_3 \\ C_2H_5 \end{matrix} > CO$, by reduction with hydrogen. Oxidizing agents convert it into the ketone. The physical properties of the butyl alcohols are given in the table in section **65**.

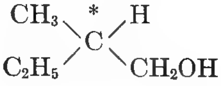
61. Tertiary Alcohols. — To the fourth butyl alcohol is assigned the formula $(CH_3)_3COH$. It is called tertiary butyl alcohol. An alcohol which contains the group $\equiv COH$ linked to *three* radicals is called a tertiary alcohol. The reactions and methods of preparing tertiary butyl alcohol are in accord with this view of its structure. When oxidized it is converted into acetone and carbon dioxide. The oxidation brings about a separation of the carbon atoms, as there is no hydrogen joined to the carbon atom with which the hydroxyl group is in combination. All tertiary alcohols undergo decomposition when oxidized, and compounds containing fewer carbon atoms than the alcohol are formed.

The ease with which tertiary alcohols react with acids is noteworthy. The primary butyl alcohols are not affected when distilled with concentrated hydrochloric acid. The tertiary alcohol, on the other hand, is converted into a chloride by the acid at room temperature. The ease with which the reverse action takes place — the conversion of the halide into alcohol — is markedly different in the two cases. The bromides of the primary butyl alcohols are decomposed by water only at high temperatures and then slowly. *ter*-Butyl bromide is converted into the alcohol by cold water. The iodide reacts even more readily. In reactivity of the hydroxyl group the secondary alcohols stand between the primary and tertiary alcohols.

62. Amyl Alcohols, $C_5H_{11}OH$. — The structural formulas of the amyl alcohols can be readily deduced by substituting hydroxyl groups in the three pentanes, replacing in each case the hydrogen atoms that bear different relations to the molecule. The application of the structure theory to the case of the amyl alcohols leads to the conclusion that eight alcohols of the formula $C_5H_{11}OH$ are possible. Eight alcohols, the reactions of which are in accord with the structural formulas deduced in this way, are known. The most important of these are the two that are found in fusel oil and in recently distilled whisky and brandy. The mixture of amyl alcohols obtained as the result of the fermentation of sugars in the preparation of ethyl alcohol, consists of about 80–90 per cent isoamyl alcohol, $(CH_3)_2CHCH_2CH_2OH$, and 10-20 per cent active amyl alcohol, $\begin{matrix}CH_3\\C_2H_5\end{matrix}>CHCH_2OH$. The latter is so called because it rotates the plane of polarized light. They are both primary alcohols — a fact which is shown by a study of the products formed from them on oxidation. The two alcohols yield aldehydes and acids which contain five carbon atoms. Isoamyl alcohol has a characteristic unpleasant odor, is poisonous, boils at 131°, and is soluble in 50 parts of water. It causes, in part, the disagreeable effects of intoxication by brandy, etc.

63. Optical Activity: Stereo-chemistry. — The study of active amyl alcohol and other substances that rotate the plane of polarized light, has led to the discovery of a class of isomerism which is not explained by the structure theory of organic compounds as it has been developed up to this point. Three amyl alcohols are known to which the structure  must be given. Their chemical properties are all in accord with this view of their structure. They differ, however, in their effect on polarized light. One alcohol rotates the plane of polarization to the right, one to the left, and the third is without effect. Those which rotate the plane of polarization are said to be *optically active.* As the differences in properties observed in these compounds are all of a physical nature, it might be assumed that these differences resulted from varying arrangements of the molecules and that the cause was purely physical. We are familiar with inorganic substances which crystallize in two forms possessing markedly different physical properties. But this can not be the explanation in the case of the amyl alcohols under consideration, as their characteristic action on polarized light is not affected by converting them into vapor. Properties which are dependent upon molecular aggregation disappear when the substance possessing these properties is converted into vapor. For example, the vapor of red phosphorus and that of yellow phosphorus is the same. Further, optically active compounds exhibit their characteristic effect on polarized light when they are in solution. In this condition free molecular motion is probably possible.

An extension of the structure theory serves to explain adequately the isomerism of the amyl alcohols and other optically active compounds. This extension takes into account the arrangement of the atoms in space. Many compounds are known which resemble the amyl alcohols in their action on polarized light. An examination of the structure of these compounds brings out the fact that they all contain a carbon atom to which are joined four different atoms or groups. Such a carbon atom is said to be *asymmetric.* In the case of active amyl alcohol there is one carbon atom which is in combination with the groups CH_3, C_2H_5, H, and CH_2OH. This asymmetric atom is marked with a * in the formula



A consideration of the possibilities of the arrangement of such a compound as this in space leads to the conclusion that isomerism should exist. Such an arrangement can not be readily illustrated on a plane surface, as it involves three dimensions. It can be appreciated best by considering a carbon atom as placed in the center of a regular tetrahedron, the affinities of the carbon atom being directed to the four angles of the tetrahedron. Such an arrangement is represented by figure 1.[1] If the affinities of a carbon atom are directed in this way, isomerism among substitution-products is possible, only in the case where the four atoms or groups in combination with the carbon atom are different. The isomerism in the case of compounds with four different atoms is represented by figure 2 and figure 3: —

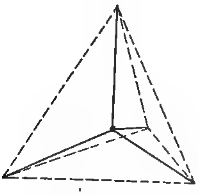


FIGURE 1

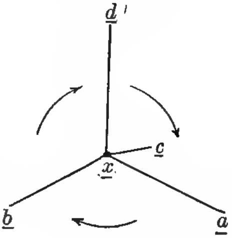


FIGURE 2

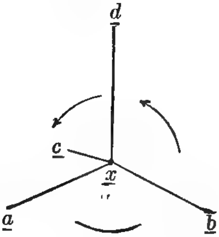


FIGURE 3

The two arrangements are not identical, as they can not be superimposed. They bear to each other the relation of the right and the left hand; of an object and its reflection in a mirror. Suppose that a ray of polarized light passes through the two molecules represented by figure 2 and figure 3, the direction of the advancing beam being, in both cases, along the line *cx*. Further, suppose that the atoms situated at *a*, *b*, and *d* cause the plane of the vibrations to be turned in the direction which is indicated by passing from *a* to *b* to *d*. In the case of the configuration represented by figure 2 the rotation would be in the direction of the motion of the hands of a clock; in the second case, figure 3, the rotation would be in the opposite direction. Substances which rotate the plane of polarization in the first way, when they are examined in a polariscope, are said to be dextrorotatory. Those which rotate the plane of polarization in the opposite direction are said to be levorotatory. A mixture of the two optically active compounds in equal amounts produces what is called the inactive compound. The mixture is inactive as the extent to which the plane of polarization is rotated is the same in the case of the two isomers. The three forms are indicated by prefixing to the name of the compound the letters *d*, *l*, or *i*: thus, *d*-amyl alcohol. The important subject of optical activity will be discussed more in detail later **(238, 249, 250)**.

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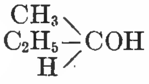
[1] The space relations involved can be more readily understood by a study of models. These can be made from pieces of cork of different size or shape, and stout wires pointed at both ends.

Higher Monatomic Alcohols

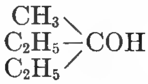
64. A large number of the homologues of methyl alcohol are known. The naturally-occurring alcohols which contain a large number of carbon atoms have the normal structure. Among these may be mentioned cetyl alcohol, $C_{16}H_{33}OH$, which is obtained from spermaceti, and myricyl alcohol, $C_{30}H_{61}OH$, which is obtained from beeswax.

Nomenclature of Alcohols.—Two systems of naming alcohols are in use. In one, the alcohol is considered as a substitution-product of methyl alcohol, which is called carbinol. Thus the alcohols having the structures represented by the formulas,



$$\begin{array}{l} CH_3\diagdown \\ C_2H_5-COH \\ \;\;H\diagup \end{array}$$

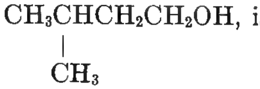
and



$$\begin{array}{l} CH_3\diagdown \\ C_2H_5-COH \\ C_2H_5\diagup \end{array}$$

are called methylethyl carbinol and methyldiethyl carbinol, respectively.

In the other system of nomenclature the name of the alcohol is formed by replacing the final *e* in the name of the hydrocarbon from which the alcohol is derived by the ending *ol*. Thus, ethyl alcohol is ethanol, and the alcohol with the structure $CH_2=CH_2CH_2OH$ is propenol. The position of the hydroxyl group is shown by adding to the name of the alcohol a number which indicates the position of the group in relation to the carbon atoms in the chain. Thus $CH_3.CH_2.CH_2.CH_2OH$ is butanol (1) and $CH_3.CH_2.CHOH.CH_3$ is butanol (2). In the case of alcohols which are not normal, that is, those in which the carbon atoms are not in a straight chain, the alcohol is considered as a substitution-product of a normal hydrocarbon which contains both alkyl groups and a hydroxyl group. In naming a compound, the longest straight chain of carbon atoms is selected as representing the carbon atoms in the hydrocarbon of which the alcohol is a derivative, thus, isoamyl alcohol, $CH_3\underset{\substack{|\\ CH_3}}{C}HCH_2CH_2OH$, is methyl (2)-butanol (4). While the common alcohols are usually called by the names which have been used in discussing them in this book, the system just described proves useful in naming alcohols which possess a more or less complex structure.



Alcohols which contain two hydroxyl groups are named in a similar way. The number of hydroxyl groups is indicated by prefixing the syllables *di*, *tri*, etc., to the termination *ol*. Thus, the diatomic alcohol $CH_3.CHOH.CHOH$ is called propanediol (1, 2).

65. Properties of the Monatomic Saturated Alcohols. — The melting-points, boiling-points, and specific gravities of some of the members of this series of alcohols are given in the following table. The data refer to the normal primary alcohols.

NORMAL PRIMARY ALCOHOLS

Name	Formula	Melting-point	Boiling-point		Specific Gravity	
Methyl	$CH_3(OH)$	—	66°		0.812	at 0° referred to water at 0°
Ethyl	$C_2H_5(OH)$	−112°	78°		0.806	
Propyl	$C_3H_7(OH)$	—	97°		0.817	
Butyl	$C_4H_9(OH)$	—	117°		0.823	
Pentyl	$C_5H_{11}(OH)$	—	138°		0.829	
Hexyl	$C_6H_{13}(OH)$	—	157°		0.833	
Heptyl	$C_7H_{15}(OH)$	—	176°		0.836	
Octyl	$C_8H_{17}(OH)$	—	195°		0.839	
Nonyl	$C_9H_{19}(OH)$	−5°	213°		0.842	
Decyl	$C_{10}H_{21}(OH)$	+7°	231°		0.839	
—	—	—	—		—	
Dodecyl	$C_{12}H_{25}(OH)$	24°	143°	at 15 mm. pressure	0.831	at the melting-point referred to water at 4°
—	—	—	—		—	
Tetradecyl	$C_{14}H_{29}(OH)$	38°	167°		0.824	
—	—	—	—		—	
Cetyl	$C_{16}H_{33}(OH)$	50°	190°		0.818	
—	—	—	—		—	
Octadecyl	$C_{18}H_{37}(OH)$	59°	211°		0.813	

An examination of the table shows that the increase in boiling-point as we pass from one member to the next in the series up to the alcohol with ten carbon atoms is nearly constant, 18° to 20°. The difference between the boiling-points of methyl alcohol and ethyl alcohol is only 12°, however. Irregularities like this are noticed in other homologous series. The difference between the boiling-points of adjacent members of the series, which contain a large number of carbon atoms, is less than 18°. As the molecule increases in weight, the introduction of one carbon and two hydrogen atoms has less effect on the physical properties of the resulting molecule. This fact is observed in other homologous series. The change in the specific gravity with increase in molecular weight shows some regularity if we disregard methyl alcohol.

The effect of structure on the physical properties is shown in the following table of the properties of the isomeric butyl alcohols: —

BUTYL ALCOHOLS

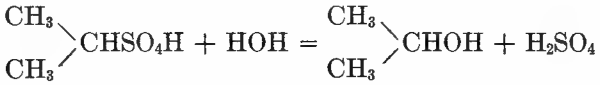
Name	Formula	Boiling-point	Specific Gravity
Normal butyl	$CH_3CH_2CH_2CH_2OH$	117°	0.824(0°)
Isobutyl	$(CH_3)_2CHCH_2OH$	106°	0.817(0°)
Secondary butyl	$CH_3CH_2CHOHCH_3$	99°	0.827(0°)
Tertiary butyl	$(CH_3)_3COH$	83°	0.780(26°)

The most notable fact observed in this table is that the tertiary alcohol has the lowest boiling-point and the primary normal alcohol the highest boiling-point. The student should compare the relations observed here with those that exist in the case of the isomeric pentanes.

66. General Methods of Preparing Alcohols. — It has already been stated that an alcohol can be prepared by replacing a halogen atom in alkyl halides by a hydroxyl group. This replacement can be affected by treating the halide with water or a metallic hydroxide. The preparation of methyl alcohol from methyl iodide is typical: —

$$CH_3I + AgOH = CH_3OH + AgI$$

The readiness with which this reaction takes place varies with the nature of the group and with the halogen. Iodides react more readily than the bromides, which, in general, are more reactive than the chlorides. This method of preparation is an example of a general method of wide applicability. The alkyl halides are ethereal salts of the alcohols and the hydrides of the halogens, — ethyl iodide is the ethereal salt, or ester, made from ethyl alcohol and hydriodic acid. Other acids form ethereal salts; ethyl sulphate, acid ethyl sulphate, ethyl nitrate, ethyl acetate, etc., are well known substances. These esters are hydrolyzed by water just as ethyl iodide is, and alcohol and the corresponding acid are formed. This reaction — the hydrolysis of an ester — serves, therefore, as a convenient way of preparing alcohols. The preparation of isopropyl alcohol by means of the following reaction is an illustration of the method: —



$$\begin{matrix} CH_3 \searrow \\ CH_3 \nearrow \end{matrix} CHSO_4H + HOH = \begin{matrix} CH_3 \searrow \\ CH_3 \nearrow \end{matrix} CHOH + H_2SO_4$$

It will be remembered that acid esters of sulphuric acid can be prepared by the action of the acid on unsaturated hydrocarbons. The preparation of alcohols from unsaturated hydrocarbons through the esters of sulphuric acid is a convenient method, as the esters of acids which contain oxygen are much more easily hydrolyzed than are the esters of the halogen hydrides. Acid ethyl sulphate is readily hydrolyzed when boiled with water. Ethyl acetate is converted into ethyl alcohol and sodium acetate when warmed with an aqueous solution of sodium hydroxide.

Alcohols can also be prepared by reducing aldehydes. This reaction is the reverse of that by which primary alcohols are converted into aldehydes by oxidation. As a consequence, primary alcohols are obtained. When aldehyde is treated with sodium amalgam, or a mixture of aldehyde vapor and hydrogen is passed over finely divided nickel, alcohol is formed: —

$$CH_3CHO + 2\,H = CH_3CH_2OH$$

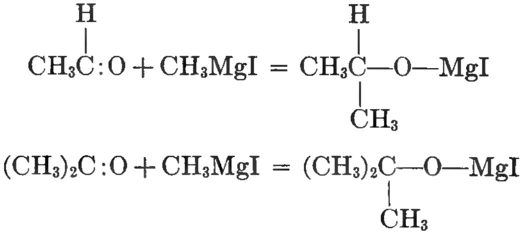
The reduction of ketones in the same manner yields secondary alcohols: —

$$(CH_3)_2CO + 2\,H = (CH_3)_2CHOH$$

Secondary and tertiary alcohols can be prepared from aldehydes and ketones, respectively, by means of zinc alkyls (**326**) or the compounds formed from the alkyl halides and magnesium. This latter method was discovered by Grignard. As has already been pointed out, when magnesium is added to a solution of an alkyl halide in ether or other appropriate solvent, the metal and the halide unite and form an addition-product: —

$$CH_3I + Mg = CH_3MgI$$

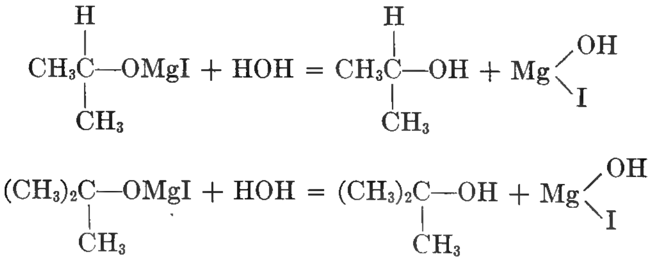
The compound so formed will unite with an aldehyde or a ketone and a second addition-product is obtained. The addition is probably brought about as the result of the presence in the aldehyde or ketone of the group $C=O$. In the addition, the double linking between the carbon and oxygen atom is broken; the alkyl group joins to the carbon atom and the magnesium and halogen to the oxygen. The reaction is represented by the following equations: —



$$\mathrm{CH_3\overset{H}{\overset{|}{C}}{:}O + CH_3MgI = CH_3\overset{H}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}—O—MgI}$$

$$\mathrm{(CH_3)_2C{:}O + CH_3MgI = (CH_3)_2\underset{\underset{CH_3}{|}}{C}—O—MgI}$$

These addition-products are decomposed by water thus: —



$$\mathrm{CH_3\overset{H}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}—OMgI + HOH = CH_3\overset{H}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}—OH + Mg\genfrac{}{}{0pt}{}{OH}{I}}$$

$$\mathrm{(CH_3)_2\underset{\underset{CH_3}{|}}{C}—OMgI + HOH = (CH_3)_2\underset{\underset{CH_3}{|}}{C}—OH + Mg\genfrac{}{}{0pt}{}{OH}{I}}$$

In the case of the aldehyde a secondary alcohol is obtained: the ketone yields a tertiary alcohol. From an aldehyde we obtain a primary alcohol by reduction, and a secondary alcohol by making use of the Grignard reaction. In the same ways we can convert a ketone into a secondary or tertiary alcohol. The Grignard reaction is of great value in synthetic organic chemistry. It has largely replaced the use of the zinc alkyls on account of its being more convenient and more widely applicable. It can be used to prepare compounds other than alcohols.

67. Reactions of Alcohols of Analytical Significance. — A number of reactions of alcohols have been described in connection with the consideration of the members of this series. A few of these are of special value in determining whether an unknown substance is an alcohol. All alcohols react with sodium with the evolution of hydrogen. In certain cases gentle heat is necessary to bring about the reaction. In testing a substance for the presence of a hydroxyl group in this way, it is necessary to make sure that the substance is free from water. As many substances which are not alcohols contain a hydroxyl group, and, consequently, react with sodium, and as certain compounds which do not contain this group show a similar reaction, the formation of hydrogen when an unknown substance is treated with sodium, is not a proof that the substance is an alcohol. The test is, however, of value. If no reaction takes place with the metal, the substance is not an alcohol.

Many alcohols dissolve in concentrated sulphuric acid as the result of the formation of alkyl sulphuric acids. Others are converted into unsaturated hydrocarbons by this reagent, especially if the temperature is allowed to rise as the result of the chemical reaction between the two substances. The alcohols of high molecular weight do not react readily with concentrated sulphuric acid, and in certain cases are insoluble. The test with this acid is not conclusive, therefore, although it is usually made and is often of value as confirmatory evidence. Many compounds which contain oxygen, either in the form of a hydroxyl group or when in combination with carbon in other ways, dissolve in concentrated sulphuric acid.

Alcohols react with the chlorides of acids. In applying this reaction in testing for alcohol, acetyl chloride is frequently used. Most alcohols react with acetyl chloride and form hydrogen chloride and the corresponding ester of acetic acid. The reaction between ethyl alcohol and acetyl chloride is expressed by the equation,

$$C_2H_5OH + CH_3COCl = CH_3COOC_2H_5 + HCl$$

The evolution of hydrogen chloride when a substance is treated with acetyl chloride is evidence that it may be an alcohol. The esters formed are usually insoluble in water, and, in most cases, possess characteristic odors. A positive test is not, however, conclusive as certain compounds which contain a hydroxyl group and are not alcohols act in the way described.

The most characteristic reaction of the monatomic alcohols is their behavior when heated with an aqueous solution of hydrobromic acid which is saturated at its boiling-point — the so-called constant boiling mixture which contains about 49 per cent of hydrogen bromide. When heated to boiling with this reagent monatomic alcohols are converted into bromides. Whether a reaction has taken place can be easily told. The bromides are all insoluble in and heavier than water, whereas the monatomic alcohols are all lighter than water.

PROBLEMS

1. Write equations for reactions by which alcohols can be prepared.

2. Write equations for the reactions which are characteristic of (*a*) the three classes of alcohols, (*b*) primary alcohols, (*c*) secondary alcohols, and (*d*) tertiary alcohols.

3. (*a*) Write the graphic formulas of the alcohols of the composition $C_6H_{13}OH$. (*b*) Name each alcohol according to the two systems explained in section **64**.

4. Write equations, using graphic formulas, for reactions by which *n*-propyl alcohol may be converted into (*a*) isopropyl alcohol, (*b*) *n*-butyl alcohol, (*c*) ethane, (*d*) ethyl alcohol, (*e*) propylene bromide, (*f*) isopropyl iodide, (*g*) propine, (*h*) hexane, and (*i*) isopropyl sulphuric acid.

5. How could you distinguish by a chemical test most conveniently in the laboratory (*a*) hexyl alcohol from hexylene, (*b*) *ter*-butyl alcohol from *iso*-amyl alcohol, (*c*) acetic acid from propyl alcohol, (*d*) methyl alcohol from ethyl alcohol?

6. How could you determine approximately the amount of alcohol in a mixture of alcohol and gasoline?

7. A compound of the composition $C_4H_{10}O_3$ was converted into one of the composition $C_6H_{14}O_5$ when treated with acetyl chloride. How many alcoholic hydroxyl groups did the original substance contain?

8. Write reactions by which acetylene may be converted into ethyl alcohol.

9. A compound of the composition $C_3H_8O_2$ was converted by phosphorus trichloride into one of the composition $C_3H_6Cl_2$. Write the graphic formulas of the two compounds.

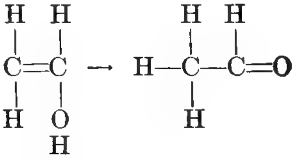
10. Write the graphic formulas of the substances which can be formed theoretically as the result of the oxidation of (*a*) $CH_3.CHOH.CH_2CH_3$, (*b*) $CH_3.CH_2.CH_2OH$, and (*c*) $CH_2OH.CHOH.CH_3$.

CHAPTER VI

UNSATURATED ALCOHOLS. POLYATOMIC ALCOHOLS

68. A number of alcohols which are derivatives of the unsaturated hydrocarbons are known. The chemistry of these compounds will be illustrated by a consideration of a few typical members of the series.

Vinyl Alcohol, $CH_2=CHOH$, which is the hydroxyl derivative of ethylene, has never been isolated. Reactions which should produce a compound of this structure lead to the formation of aldehyde; it is probable that vinyl alcohol is first produced, and that aldehyde is formed by a rearrangement of the atoms in the molecule: —



$$\begin{array}{ccc} \mathrm{H}\quad\mathrm{H} & & \mathrm{H}\quad\mathrm{H} \\ |\quad\;\; | & & |\quad\;\; | \\ \mathrm{C{=}C} & \rightarrow & \mathrm{H{-}C{-}C{=}O} \\ |\quad\;\; | & & | \\ \mathrm{H}\quad\mathrm{O} & & \mathrm{H} \\ \quad\;\;\mathrm{H} & & \end{array}$$

Rearrangements similar to this have been shown definitely to take place in the case of other compounds. No simple alcohol is known in which a hydroxyl group is in combination with a carbon atom united to another carbon atom by a double bond. Experiments indicate that vinyl alcohol may be present in moist ether which has been exposed to sunlight, but no satisfactory proof has been given. The vinyl radical $CH_2=CH-$ occurs in a number of compounds.

69. Allyl Alcohol, $CH_2=CHCH_2OH$. — According to the structure theory three monohydroxyl derivatives of propylene are possible: $CH_2=CHCH_2OH$, $CH_2=COHCH_3$, and $CHOH=CHCH_3$. Allyl alcohol, the structure of which is represented by the first formula, is the only one known. In the second and third formulas the hydroxyl groups are represented in combination with a doubly-linked carbon atom. Attempts to prepare these compounds have yielded results similar to those obtained in the case of vinyl alcohol: isomeric compounds have been obtained in both cases, as the result of molecular rearrangement. Derivatives of these alcohols are known, however.

Allyl alcohol occurs in small quantities in pyroligneous acid. A number of derivatives of allyl alcohol occur in nature. Allyl sulphide, $(C_3H_5)_2S$, is the chief constituent of oil of garlic. Allyl isosulphocyanate, C_3H_5NCS, occurs in mustard seed in combination with glucose. Allyl alcohol is a colorless liquid of pungent odor, which mixes with water in all proportions and boils at 96.6°. Its specific gravity at 0° is 0.872. It can be prepared in a number of ways which are suggested by a consideration of its structural formula. It is most conveniently prepared by heating glycerol with oxalic acid. The reaction, which is a complicated one, will be discussed later (**80**).

The reactions of allyl alcohol are in accord with the structure assigned to it. The presence of a hydroxyl group is shown by the fact that the substance reacts with sodium with the evolution of hydrogen, and by the fact that allyl acetate is formed when it is treated with acetyl chloride. The presence of a double bond in allyl alcohol is shown by the fact that it unites readily with two atoms of chlorine, bromine, or iodine. It shows, in general, the reactions which are characteristic of ethylene and its homologues. The structure of the alcohol follows from the reactions which have been mentioned, and from the fact that by careful oxidation it can be converted into an aldehyde and an acid which contains the same number of carbon atoms as the alcohol. It contains, therefore, a primary alcohol group, $-CH_2OH$. Allyl alcohol, when reduced by hydrogen formed by the action of zinc on dilute sulphuric acid, is converted into *n*-propyl alcohol. This indicates that the hydroxyl group in allyl alcohol is joined to an end carbon atom.

70. Propargyl Alcohol, $HC{\equiv}C.CH_2OH$, is an illustration of an alcohol derived from a hydrocarbon of the acetylene series. The compound is a colorless liquid of peculiar odor, which dissolves in water. It boils at 115°. It can be prepared by methods which involve the principles made use of in the preparation of alcohols and of triple-bonded compounds. One method is illustrated by the following formulas: —

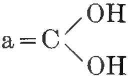
$$CH_2Br.CHBr.CH_2Br \xrightarrow{KOH} CH_2{:}CBr.CH_2Br \xrightarrow{H_2O}$$

$$CH_2{:}CHBr.CH_2OH \xrightarrow{KOH} CH{:}C.CH_2OH$$

The method involves the preparation of an alcohol by replacing a halogen atom by the hydroxyl group, and the establishment of the triple bond by the removal of two molecules of hydrogen bromide from adjacent carbon atoms. Propargyl alcohol exhibits the reactions of a primary alcohol, which have been frequently emphasized. It shows its relation to acetylene by forming well characterized metallic derivatives. The copper compound, $CuC{\equiv}C.CH_2OH$, is a canary-yellow powder which is formed by treating an ammoniacal solution of cuprous chloride with the alcohol. It explodes when heated.

POLYATOMIC ALCOHOLS

71. The polyatomic alcohols are alcohols which contain more than one hydroxyl group. Glycol, $C_2H_4(OH)_2$, is an example of a diatomic alcohol, and glycerol, $C_3H_5(OH)_3$, of a triatomic alcohol. Alcohols are known which contain four, five, and six hydroxyl groups. These are called tetratomic, pentatomic, and hexatomic alcohols, respectively.

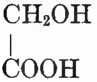
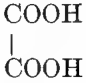
The simplest diatomic alcohol would have the structure $CH_2(OH)_2$. This compound does not exist, although derivatives in which the two hydrogen atoms of the hydroxyl groups are replaced by radicals are known. It has been stated that, in general, two hydroxyl groups can not exist in combination with a single carbon atom. When an attempt is made to prepare such a compound, instead of obtaining the grouping represented by the formula  $=C\begin{smallmatrix}\diagup OH\\ \diagdown OH\end{smallmatrix}$ the elements of water are lost and the resulting compound contains the group $=C=O$. The polyatomic alcohols contain, therefore, at least as many carbon atoms as hydroxyl groups.

72. Glycol, $C_2H_4(OH)_2$, is the first member of a series of diatomic alcohols. Derivatives of propane having the formulas $CH_3.CHOH.CH_2OH$ and $CH_2OH.CH_2.CH_2OH$, are known. As the chemical properties of these and similar compounds resemble closely those of glycol, the latter compound only will be described here.

Glycol is a colorless liquid which mixes with water and has a sweet taste. It boils at 197° and after solidification in a freezing mixture melts at — 11.5°. It is heavier than water, as it has the specific gravity 1.125 at 0°. It will be recalled that the monatomic alcohols are lighter than water.

Glycol is prepared from ethylene bromide by replacing the halogen atoms by hydroxyl groups. This exchange can be effected by heating the bromide either with water at a high temperature in a sealed tube, or with a solution of sodium carbonate in an open vessel. As the reaction takes place slowly, glycol is sometimes prepared by heating ethylene bromide with silver or potassium acetate and then hydrolyzing the resulting acetate. The changes are represented by the equations, —

$$C_2H_4Br_2 + 2CH_3COOAg = C_2H_4(OOCCH_3)_2 + 2AgBr$$
$$C_2H_4(OOCCH_3)_2 + 2KOH = C_2H_4(OH)_2 + 2CH_3COOK$$

The behavior of glycol with reagents indicates that the compound contains two alcoholic hydroxyl groups. With sodium it forms the compounds $CH_2OH.CH_2ONa$ and $CH_2ONa.CH_2ONa$. Phosphorus pentachloride or hydrochloric acid replaces, according to the conditions, one or two hydroxyl groups by chlorine. Fuming nitric acid and glycol form the dinitrate, $C_2H_4(NO_3)_2$. When treated with cold nitric acid one of the primary alcohol groups is oxidized to carboxyl and an acid of the structure  $\begin{array}{l}CH_2OH\\|\\COOH\end{array}$ (glycollic acid) is formed. When the mixture of the alcohol and dilute nitric acid is heated, oxalic acid  $\begin{array}{l}COOH\\|\\COOH\end{array}$ is obtained.

73. Glycerol, $C_3H_5(OH)_3$. — Glycerol, the simplest alcohol containing three hydroxyl groups, is a derivative of propane. It has been known for a long time and is commonly called glycerin. Glycerol is a viscous liquid which has the specific gravity 1.265 at 15°. It has a sweet taste; in this respect it resembles the other polyatomic alcohols. When pure, it is colorless, melts at 17° after solidification in a freezing mixture, and boils without decomposition at 290°. When distilled in the presence of salts slight decomposition takes place. Glycerol is miscible with water, alcohol, and chloroform, but is insoluble in ether. It is hygroscopic and will absorb more than one-half its weight of water from the air. Glycerol is produced in the alcoholic fermentation of sugar and, consequently, occurs in all fermented liquors. The amount of glycerol formed in the fermentation is about three per cent of the weight of the sugar.

Glycerol is obtained commercially from animal fats or from oils which occur in plants. The chief sources are tallow and olive oil. These substances consist of mixtures of compounds which are ethereal salts of glycerol and organic acids. The salts which occur in largest amounts in the fats and oils are palmitin, $(C_{15}H_{31}.COO)_3C_3H_5$, which is the glycerol salt of palmitic acid, $C_{15}H_{31}.COOH$, stearin, $(C_{17}H_{35}.COO)_3C_3H_5$, which is a glyceryl stearate, and olein, $(C_{17}H_{33}.COO)_3C_3H_5$, the glycerol ester of oleic acid — an unsaturated acid of the formula $C_{17}H_{33}.COOH$.

These esters are hydrolyzed when heated with steam or when boiled with a solution of an alkali. Esters are, in general, converted into acids and alcohols when heated with water. Ethyl acetate under these conditions yields ethyl alcohol and acetic acid: —

$$CH_3COOC_2H_5 + HOH = CH_3COOH + C_2H_5OH$$

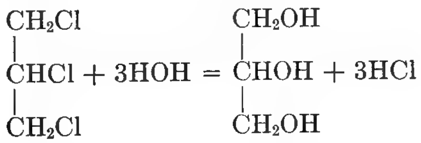
When palmitin is heated with water to a high temperature a reaction takes place which is represented by the following equation: —

$$(C_{15}H_{31}COO)_3C_3H_5 + 3HOH = 3C_{15}H_{31}.COOH + C_3H_5(OH)_3$$

Palmitic acid and glycerol are formed. When palmitin is heated with a solution of sodium hydroxide, glycerol and sodium palmitate are formed. This reaction of hydrolysis is usually called *saponification* as the sodium salt of the fatty acid formed is a *soap*. The preparation and properties of soap, and the chemical properties of fats will be described later (**96**). The reaction is introduced in this place on account of its bearing on the production of glycerol, which is obtained as a by-product in the manufacture of soap and of candles. The glycerol is separated from the aqueous liquid obtained in these processes by evaporating the solution after precipitating impurities with iron salts. Pure glycerol is obtained by distilling the residue under diminished pressure with superheated steam. The excess of water is removed by evaporating the solution *in vacuo* until the glycerol has the specific gravity of about 1.262.

Glycerol is used in large quantities in the manufacture of nitroglycerin. It is also used in the preparation of printers' ink-rolls, and, on account of its being non-volatile and hydroscopic, as an ingredient of ink used with rubber stamps. It is used in pharmacy, as a preservative for tobacco, as a sweetening agent in fermented liquors, in confectionery and preserves, and in the preparation of cosmetics.

74. Glycerol has been prepared synthetically by methods which lead to the view that it is a trihydroxyl derivative of propane. When the trichlorpropane of the structure $CH_2Cl.CHCl.CH_2Cl$ is heated with water at about 170° the halogen atoms are replaced by hydroxyl groups, the reaction being analogous to the preparation of alcohol from ethyl bromide. The equation for the reaction is, —



$$\begin{array}{l} CH_2Cl \\ | \\ CHCl \end{array} \!\!\!\!\!\!\!\! \begin{array}{l} \\ \\ + 3HOH = \end{array} \begin{array}{l} CH_2OH \\ | \\ CHOH + 3HCl \\ | \\ CH_2OH \end{array}$$

$$\begin{array}{l} CH_2Cl \\ | \\ CHCl + 3HOH \\ | \\ CH_2Cl \end{array} = \begin{array}{l} CH_2OH \\ | \\ CHOH + 3HCl \\ | \\ CH_2OH \end{array}$$

The reactions of glycerol with other substances are in accord with the structure which is arrived at from an interpretation of the methods made use of in its synthesis. The presence of three hydroxyl groups is shown by the composition of the products formed as the result of the action of the chlorides of phosphorus on glycerol. Under the proper conditions phosphorus trichloride will replace one, two, or three hydroxyl groups in glycerol by chlorine atoms. Glycerol, like other alcohols, reacts with strong inorganic acids and forms ethereal salts. When heated with hydrochloric acid, compounds are formed in which one or two hydroxyl groups are replaced by halogen atoms. These substances which have the structure represented by the formulas $CH_2OH.CHOH.CH_2Cl$ and $CH_2Cl.CHOH.CH_2Cl$ are called monochlor and dichlorhydrin, respectively. Hydrobromic acid forms similar compounds.

75. The changes which glycerol undergoes with hydriodic acid are different from those which take place with hydrochloric acid, on account of the fact that hydriodic acid is a strong reducing agent. When glycerol is heated with a concentrated aqueous solution of hydriodic acid the products formed are allyl iodide and propylene. In the presence of an excess of the acid isopropyl iodide results. Allyl iodide and isopropyl iodide are most conveniently prepared by these reactions. The separate chemical reactions by which these substances are formed are not definitely known. In all, however, the hydriodic acid acts as a reducing agent. The effect on the result of the relation between the quantities of glycerol and acid used is shown by the following equations: —

$$CH_2OH.CHOH.CH_2OH + 3HI = CH_2{:}CH.CH_2I + 3H_2O + I_2,$$
$$CH_2OH.CHOH.CH_2OH + 4HI = CH_2{:}CH.CH_3 + 3H_2O + 2I_2,$$
$$CH_2OH.CHOH.CH_2OH + 5HI = CH_3.CHI.CH_3 + 3H_2O + 2I_2.$$

It has already been pointed out that the equations used to represent the reactions studied in organic chemistry frequently do not have the quantitative significance that similar equations in inorganic chemistry have. The reactions which organic substances undergo are often complicated in that a number of reactions which can be represented by separate equations are taking place simultaneously. The action of hydriodic acid on glycerol is an example of such a reaction. Similar reactions are known to take place between inorganic compounds. The student will recall what takes place when potassium iodide is treated with concentrated sulphuric acid. The hydriodic acid produced reduces sulphuric acid, and sulphur dioxide, sulphur, and hydrogen sulphide are formed. The equations written for these reactions are, —

$$H_2SO_4 + 2HI = SO_2 + 2H_2O + I_2,$$
$$H_2SO_4 + 6HI = S + 4H_2O + 3I_2,$$
$$H_2SO_4 + 8HI = H_2S + 4H_2O + 4I_2.$$

If it is desired to use such a reaction as a means of preparing one of the reduction products, careful study of the conditions under which the reaction takes place is necessary in order to discover under what conditions the yield of the desired compound is greatest. To obtain a satisfactory yield of allyl iodide from glycerol, the latter is distilled with phosphorus iodide. It is probable that the three hydroxyl groups are first replaced by iodine and the resulting compound then loses two iodine atoms: —

$$CH_2I.CHI.CH_2I = CH_2{:}CH.CH_2I + I_2.$$

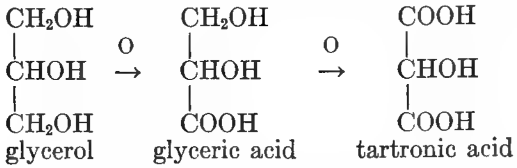
When a larger proportion of phosphorus iodide is used, and water is present which converts the iodide into hydriodic acid, the chief product of the reaction is isopropyl iodide.

76. Nitric acid converts glycerol into a mononitrate, $C_3H_5(OH)_2NO_3$, and a trinitrate, $C_3H_5(NO_3)_3$. When nitric acid diluted with three parts of water is used the mononitrate is formed. The trinitrate, which is usually called *nitroglycerin*, is prepared by dropping glycerin slowly into a mixture of concentrated sulphuric acid and fuming nitric acid, which is kept at a temperature below 20°. The sulphuric acid is used as a dehydrating agent. It unites with the water formed in the reaction, and thus prevents the dilution of the nitric acid. When the reaction is complete the mixture is poured into water, and the nitroglycerin which separates is washed with water, and finally with a solution of sodium carbonate to remove acid.

Nitroglycerin is a heavy, colorless, oily liquid, which has a sweet taste and, as ordinarily prepared, a pale yellow color. It freezes at about 8°, melts at about 12°, and explodes when heated to 180°. Small quantities burn in the open air without explosion. Nitroglycerin is very sensitive to shocks, and can readily be exploded by a sharp blow. It is a powerful poison, resembling strychnine somewhat in its physiological effects. It is used as a remedy in heart disease, and is injected into the blood in cases of poisoning by carbon monoxide or water-gas.

The chief use of nitroglycerin is as an explosive. When mixed with certain porous substances, such as clay, sawdust, or wood-pulp, it is called *dynamite*. Various explosives are made by mixing nitroglycerin with other substances. Blasting gelatin is made by dissolving in nitroglycerin soluble nitrocellulose, which is a compound made by the treatment of cotton with nitric acid. The smokeless powder which is called *cordite* is a mixture of nitroglycerin, nitrocellulose, vaseline, and acetone.

77. Glycerol can be readily oxidized. When, for example, glycerol is placed on powdered potassium permanganate the mixture soon ignites, and the glycerol burns with a blue flame. By careful regulation of the oxidation, glyceric acid and tartronic acid may be formed. These acids have been shown to have the structures represented by the formulas given below: —



$$\begin{array}{c} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} \xrightarrow{O} \begin{array}{c} CH_2OH \\ | \\ CHOH \\ | \\ COOH \end{array} \xrightarrow{O} \begin{array}{c} COOH \\ | \\ CHOH \\ | \\ COOH \end{array}$$

The change in each case consists in the conversion of a primary alcohol group into carboxyl — the group characteristic of acids. These transformations are further evidence of the correctness of the structure assigned to glycerol.

Higher Polyatomic Alcohols

78. Alcohols are known which contain four, five, six, and seven hydroxyl groups. Some of these occur in nature and some have been made synthetically. *Erythritol* is a tetratomic alcohol and has the structure represented by the formula $CH_2OH.CHOH.CHOH.CH_2OH$. *Adonitol*, *xylitol*, and *arabitol* are pentatomic alcohols of the structure $CH_2OH(CHOH)_3CH_2OH$. Examples of hexatomic alcohols are *mannitol*, *dulcitol*, and *sorbitol.* These alcohols occur in nature in the sap of certain trees. Sorbitol is also found in the berries of the mountain ash, and in many fruits. Hexatomic alcohols may be made in the laboratory by the reduction of certain sugars. These reactions will be discussed when the carbohydrates are considered.

The names formerly given to these higher polyatomic alcohols ended in the syllable *ite:* sorbitol was called sorbite, and mannitol, mannite, and so forth.

PROBLEMS

1. Write equations for reactions by which allyl alcohol may be prepared.

2. By what simple chemical tests can allyl alcohol be distinguished from (*a*) propyl alcohol, (*b*) propylene, (*c*) propargyl alcohol?

3. Write equations, using graphic formulas, for reactions by which allyl alcohol may be converted into (*a*) glycerol, and (*b*) an acid. What reagents can be used to effect the changes indicated?

4. Write graphic formulas for all the oxidation products of glycol which are theoretically possible.

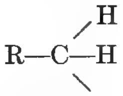
5. Propylene glycol has the formula $CH_3.CHOH.CH_2OH$: write equations for reactions by which it may be prepared from propyl alcohol.

CHAPTER VII

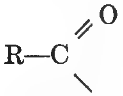
MONOBASIC ACIDS

79. In the last two chapters the important class of organic compounds known as alcohols was described. The characteristic chemical properties of these compounds are due to the fact that they all contain a hydroxyl group. Many compounds of importance are known which contain this group, but which differ markedly from the alcohols in their chemical behavior with other substances. These substances can be separated into well defined classes. The members of one of these classes are known as acids. It has been pointed out that the reactions of a group of atoms, such as the hydroxyl group, are largely determined by the nature of the radical with which the group is in combination. The fact is well shown in the case of alcohols and acids. The radicals which are present in alcohols contain carbon and hydrogen; those present in acids contain oxygen in addition to these two elements. Ethyl alcohol, $CH_3CH_2.OH$, is a typical alcohol, acetic acid, $CH_3CO.OH$, is a typical acid. The replacement of two positive hydrogen atoms by a negative oxygen atom results in the production of a radical which is itself negative. The words positive and negative, as used in this connection, are somewhat indefinite terms. They have the significance that they have when we speak of sodium as a positive element and chlorine as a negative element. The terms are purely relative. The element antimony, for example, is negative when we compare it with sodium; it is positive, however, to chlorine. The standard used in the consideration of organic compounds is hydrogen. If a group is more positive than hydrogen it is said to be positive; if it is less positive than hydrogen it is said to be negative. Hydrogen is selected as the standard on account of the fact that the compound formed by the union of this element with the hydroxyl group, water, is neither an acid nor a base. If one hydrogen atom in water is replaced by what is called here a positive element, sodium for example, the compound formed (NaOH) is a base; if on the other hand it is replaced by a negative element, such as chlorine, the resulting compound is an acid (ClOH).

Compounds which contain the positive alkyl groups united with hydroxyl show properties which resemble to some extent those of bases, whereas the compounds which contain the negative groups united with hydroxyl resemble the inorganic acids. The relation between the two kinds of groups is shown by the formulas, —



alkyl radical



acyl radical

The letter R represents any alkyl radical. As the radicals present in acids occur in many compounds they have been given the general name *acyl.*[1] The specific name for any acyl radical is derived from the name of the acid in which it occurs. Thus, acetic acid, $CH_3CO.OH$, contains the acetyl radical (CH_3CO); propionic acid, $C_2H_5CO.OH$, the propionyl radical (C_2H_5CO); and butyric acid, $C_3H_7CO.OH$, the butyrl radical (C_3H_7CO). A primary alcohol, as has been shown, contains the group — CH_2OH, and an acid contains the group — COOH. The latter is called the *carboxyl* group. The acids are thus carboxyl derivatives of the hydrocarbons. Those which contain one such group and are derived from the hydrocarbons of the methane series are called *fatty acids.* This name was given to these acids as many of them were first obtained as the result of the decomposition of fats.

Many organic acids occur in nature, either free, or in the form of salts or compounds with alcohols. They are formed in growing plants, and as the result of the fermentation of the sugars which occur in fruits. They occur as glycerol esters in fats and oils. From tallow, butter, olive oil, etc., can be obtained a large number of acids by heating with steam; the glycerol esters are hydrolyzed and the acids set free.

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[1] Acyl radicals should not be confused with the acid radicals which exist as ions; CH_3CO is the acyl radical of acetic acid, whereas CH_3COO is the negative ion of this acid.

When arranged according to their chemical composition the fatty acids form an homologous series. The first member in the series has the composition represented by the formula CH_2O_2. It is known as formic acid. As it contains the carboxyl group, its structural formula is H.COOH. The second member in the series is acetic acid, $CH_3.COOH$, the third propionic acid, $C_2H_5.COOH$, etc. A few of the more important acids will be considered in some detail.

80. Formic Acid, H.COOH. — Formic acid (from Latin, *formica,* ant) occurs in nettles, bees, and ants. The irritation produced as a result of the sting of these and other insects is apparently due to the presence of formic acid in the liquid which is injected into the skin. Formic acid is a colorless, mobile, hygroscopic liquid. When pure, it melts at 8.5°, boils at 101°, and has the specific gravity 1.241 at 0°. It causes painful blisters when left in contact with the skin. The acid has a pungent, irritating odor resembling that of sulphur dioxide. Formic acid can not be separated from water by fractional distillation as it forms a constant-boiling mixture with water. The mixture boils at 107.1°, and contains 77.5 per cent of formic acid.

Formic acid may be obtained by the direct oxidation of methyl alcohol. Sodium formate is prepared industrially by heating sodium hydroxide with carbon monoxide under pressure:

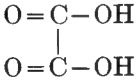
$$CO + NaOH = H.COONa$$

The reaction recalls the action of carbon dioxide and other gaseous acid anhydrides on solutions of sodium hydroxide: —

$$CO_2 + 2NaOH = Na_2CO_3$$

In both cases salts are formed. Carbon monoxide may thus be considered as the anhydride of formic acid, although it does not react with water to form the acid, nor with an aqueous solution of a base to form a salt. Formic acid can be distilled without decomposition, but when heated with a dehydrating agent it is decomposed into carbon monoxide and water. When finely divided metallic rhodium is added to formic acid the latter decomposes spontaneously into carbon monoxide and water.

Formic acid is usually prepared in the laboratory by distilling a mixture of oxalic acid and glycerol. Oxalic acid has the structure represented by the formula,

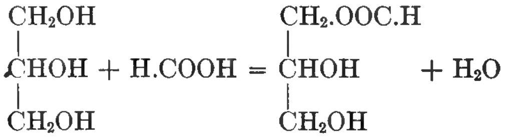


$$\begin{array}{l} O=C-OH \\ \quad\;\; | \\ O=C-OH \end{array}$$

It consists of two carboxyl groups in combination. When the acid is heated alone, a small amount of formic acid is produced as the result of the elimination of carbon dioxide:—

$$(COOH)_2 = CO_2 + H.COOH$$

As most of the acid sublimes unchanged, it is mixed with glycerol, which prevents the sublimation of the unchanged oxalic acid, and allows a higher temperature to be attained. Certain intermediate reactions take place in the process on account of the fact that glycerol is an alcohol, and, consequently, forms esters with acids. A part of the formic acid produced reacts with the glycerol and forms a formate in which one of the hydroxyl groups of the alcohol is replaced by the formyl group:—



$$\begin{array}{lcl} CH_2OH & & CH_2.OOC.H \\ | & & | \\ CHOH + H.COOH & = & CHOH \qquad + H_2O \\ | & & | \\ CH_2OH & & CH_2OH \end{array}$$

This ester, called monoformin, is then hydrolyzed by the water present in the crystallized oxalic acid ($C_2O_4H_2.2H_2O$) which is added from time to time. The reaction is this case is the reverse of the one last given. The best yield of acid is obtained when the reaction is carried out at about 120°. The distillate is a dilute aqueous solution of formic acid. When the mixture of glycerol and oxalic acid is heated to 210°–260°, the monoformin undergoes a decomposition as the result of which carbon dioxide, water, and allyl alcohol are formed. The reaction furnishes the most convenient way of making this alcohol (**69**).

Formic acid and its salts, when gently heated with concentrated sulphuric acid, are decomposed and carbon monoxide is formed:—

$$H.COOH = H_2O + CO$$

The presence of carbon monoxide can be shown by the fact that the gas formed burns with a blue flame. The acid and its salts are strong reducing agents. When a formate is warmed with an ammoniacal solution of silver nitrate, silver is precipitated and the formate oxidized to a carbonate. This reaction in connection with the formation of carbon monoxide, is used as a *test for formic acid.* It is important to note that both tests should be positive as many substances reduce an ammoniacal solution of silver nitrate, and oxalic acid and other compounds yield carbon monoxide when treated with concentrated sulphuric acid.

81. Acetic Acid, $CH_3.COOH$. — Acetic acid occurs as esters in the odoriferous oils of many plants, and in fruit juices which have become sour as the result of fermentation. It is the chief acidic constituent of vinegar. Pure anhydrous acetic acid is a colorless, crystalline, hygroscopic solid, which melts at 16.7° and boils at 119°. On account of the fact that the solid resembles ice in appearance, this form of the acid is called *glacial acetic acid.* The acid blisters the skin and has a penetrating odor and sharp sour taste. At or near its boiling-point it burns with a feebly luminous flame. It is soluble in water, alcohol, and ether in all proportions, and is an excellent solvent for most organic and some inorganic substances which are insoluble or sparingly soluble in water, as, for example, sulphur and iodine.

The specific gravity of acetic acid at 15° is 1.055. When water is added to the acid the specific gravity increases to 1.075, when the aqueous solution contains 80 per cent of anhydrous acid. Further addition of water results in a decrease in specific gravity. The solution which contains 43 per cent of acetic acid has the same specific gravity as that of the pure acid.

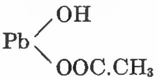
82. Vinegar. — Acetic acid is prepared industrially by the oxidation of alcohol and by the distillation of wood. By the first method, which is the one used in the manufacture of vinegar, a dilute aqueous solution of the acid is obtained, which contains many substances in small quantities in addition to acetic acid. The oxidation of alcohol to acetic acid can be effected readily by means of ordinary oxidizing agents. Atmospheric oxygen will convert an aqueous solution of alcohol into acetic acid, in the presence of spongy platinum. Industrially, the change to acetic acid is brought about by means of certain bacteria which are present in the air. The micro-organism, *microderma aceti*, which is commonly called mother of vinegar, is the chief agent involved in bringing about the change. A pure aqueous solution of alcohol will not ferment. The bacteria multiply and exercise their functions only in the presence of air, and when supplied with a soluble phosphate and with organic compounds which contain nitrogen. Such substances are present in the juices of fruits, and, consequently, when cider is left exposed to the air, fermentation takes place and the liquid becomes sour as the result of the formation of acetic acid. Vinegar is prepared in this way from cider, wine, and dilute solutions of alcohol which have been made by the fermentation of malt. The process requires several weeks for completion, as the oxygen required for the transformation is taken up only at the surface of the liquid. The vinegar prepared in this way contains from 6 to 10 per cent of acetic acid.

The fermentation of malt decoctions or diluted alcohol, is generally accomplished by the *quick vinegar process.* In this process a mixture of vinegar and the solution to be fermented is allowed to trickle slowly through tall vats nearly filled with beechwood shavings, which have been previously soaked in vinegar and are covered by the bacteria which bring about the fermentation. The vats are so arranged that a slow current of air passes through them, and care is taken to keep the temperature at as near 30° as possible. In order to increase the amount of acetic acid formed, the solutions are passed through a number of vats in succession. The percentage of acid in the final product varies ordinarily from 4 to 6 per cent. Eight to twelve days are required for the process.

The quality of vinegar is usually determined by the source from which it is prepared. While its use as a condiment is due to its being an acid, its color, aroma, and flavor are the result of the presence in it of very small quantities of esters and other substances, which vary with the source. The different kinds of vinegar can be distinguished from one another by the determination of the presence in them of substances other than acetic acid. For example, cider vinegar contains malic acid, which is present in apples; wine vinegar contains the tartaric acid and cream of tartar present in the grapes from which it was prepared; and malt vinegar contains dextrin and other substances. Spirit vinegars, so-called, are made from dilute alcohol, and lack much of the odor and flavor of fruit or malt vinegars. They are often colored with caramel and flavored with certain esters which impart to them an odor resembling that of true vinegar.

83. Preparation of Acetic Acid. — Acetic acid is prepared in large quantities by the distillation of wood. The process was described when methyl alcohol was considered (**47**). The vapor of the distillate from the wood is usually passed into milk of lime, which combines with the acid to form calcium acetate. The salt obtained by evaporating the solution to dryness is called "gray acetate of lime." Commercial acetic acid is obtained from the calcium acetate so prepared by distilling with concentrated hydrochloric acid in copper stills. The acid is a slightly-colored liquid which contains about 50 per cent of acetic acid. It may be further purified by redistilling over a little potassium bichromate, which oxidizes some of the impurities, and by filtering through charcoal.

In the preparation of the anhydrous acid a mixture of anhydrous sodium acetate and concentrated sulphuric acid is distilled. The acetate is purified either by recrystallization, or is fused to destroy the tarry matter present. Acetic acid can be freed from water by repeated distillation, as it does not form a constant-boiling mixture with water. To obtain a very pure glacial acid, a sample of acetic acid which contains a small amount of water is frozen and then allowed to partially melt. As much of the liquid as possible is poured off, and what is left is melted and frozen again. This is partially melted and the process repeated. The glacial acid can also be conveniently prepared by first determining the amount of water present in a sample of acid by an observation of the freezing-point, and then adding the calculated amount of acetic anhydride (**120**), which unites with the water present to form acetic acid. One per cent of water in acetic acid causes a depression of 2.16° in the freezing-point.

84. Uses of Acetic Acid. — Acetic acid is used in the manufacture of "white lead." When lead is exposed to the vapor of acetic acid, lead acetate is formed, which is converted into a basic carbonate by carbon dioxide and water-vapor. Many salts of acetic acid are known and a number are used extensively. *Sodium acetate,* $CH_3.COONa.3H_2O$, crystallizes well. When heated, it first melts and then solidifies when the water of crystallization has been driven off. With increase in temperature the anhydrous salt melts, and finally decomposes with the formation of sodium carbonate. *Potassium acetate* is an anhydrous salt. Lead acetate, called *sugar of lead,* $(CH_3COO)_2Pb.3H_2O$, is prepared by dissolving litharge in acetic acid; when an excess of the oxide is used, basic salts are formed. One of these, which apparently has the formula  $Pb\begin{cases}OH\\OOC.CH_3\end{cases}$ is used to clarify sugar solutions before they are analyzed. *Verdigris* is a basic acetate of copper which corresponds in composition closely to that represented by the formula $[2(CH_3COO)_2Cu\ .\ CuO]$. It is used as a green pigment. *Paris green* is a double salt which contains copper acetate and copper arsenite. One of the formulas assigned to it is $[(CH_3COO)_2Cu\ .\ Cu_3As_2O_6]$. It is prepared by adding a thin paste of verdigris in water to a boiling solution of arsenous acid which contains acetic acid. It is chiefly used to exterminate potato beetles and other insects. Small quantities of the compound find application as a pigment. The *acetates* of *iron, aluminum,* and *chromium* are extensively used as mordants in dyeing and in calico printing. When an aqueous solution of the neutral acetate of iron, chromium, or aluminum, which contains a small quantity of other salts, is heated, the acetate is decomposed and a basic salt is precipitated. This fact is made use of in quantitative analysis, in separating the trivalent from other metals, for example, in the separation of iron from manganese.

85. Synthesis of Acetic Acid. — Acetic acid may be prepared from simple substances by methods which throw light on its structure. As these methods are examples of general synthetical processes used to prepare organic acids they are of prime importance. Acetic acid may be prepared by heating alcohol with a solution of chromic acid, potassium permanganate, or other strong oxidizing agents. The reaction consists in converting the group in alcohol which is characteristic of a primary alcohol, into a carboxyl group: —

$$CH_3.CH_2OH + O_2 = CH_3.COOH + H_2O$$

As all alcohols which contain the group CH_2OH undergo this change, the reaction should be carefully noted.

A second and equally important method of preparing an acid is illustrated in the case of acetic acid by the equation, —

$$CH_3.CN + 2H_2O = CH_3.COOH + NH_3$$

Methyl cyanide is a volatile liquid which may be prepared by heating methyl iodide with potassium cyanide: —

$$CH_3I + KCN = CH_3.CN + KI$$

When methyl cyanide is heated with water, a reaction takes place according to the equation written above. Acetic acid and ammonia, which react to form ammonium acetate, are formed. The change takes place more rapidly in the presence of an alkali or an acid, either of which serves to catalyze the reaction. The change which takes place is one of hydrolysis, as the cyanide reacts with water and is converted into two other compounds. This method of preparing an acid is a general one, as all alkyl cyanides (ethyl cyanide, butyl cyanide, etc.) are hydrolyzed when boiled with an aqueous solution of an acid or base. The cyanides are frequently called *nitriles*. Methyl cyanide is called acetonitrile, on account of its relation to acetic acid. The cyanides will be discussed at length later (**196**).

86. Another interesting method which is applicable in certain cases is that discovered by Grignard. It will be recalled that this investigator showed that when magnesium is added to a solution of an alkyl halide in ether or other appropriate solvent, a compound is formed which reacts readily with other substances. If the magnesium alkyl halides so prepared are treated with carbon dioxide, the gas is absorbed and an addition-product is formed, which on treatment with water yields an acid. The reactions in the case of the preparation of acetic acid are expressed by the following equations: —

$$CH_3I + Mg = CH_3\text{—}Mg\text{—}I$$

$$CH_3\text{—}Mg\text{—}I + CO_2 = CH_3CO_2\text{—}Mg\text{—}I$$

$$CH_3CO_2\text{—}Mg\text{—}I + HOH = CH_3CO_2H + HO\text{—}\overset{M}{\cancel{H}}g\text{—}I$$

87. Reactions of Acetic Acid. — Acetic acid shows the properties which are characteristic of acids. It decomposes carbonates, forms salts with metallic hydroxides, and reacts with iron, zinc, and other metals. Acetic acid forms esters with alcohols. In order to increase the yield of the ester and the rate of the reaction, a dehydrating agent is usually added to the mixture of alcohol and acid. Ethyl acetate is prepared by warming a mixture of glacial acetic acid, alcohol, and sulphuric acid: —

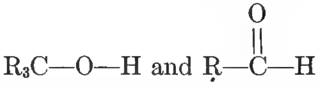
$$CH_3.COOH + C_2H_5OH = CH_3.COOC_2H_5 + H_2O$$

Acetic acid resists to a high degree the action of oxidizing agents. Its stability under these circumstances is so great that it is often used as a solvent for substances which are to be oxidized by chromic acid. When chlorine is passed into boiling acetic acid, preferably in the sunlight, the hydrogen atoms in the methyl group are, one after another, replaced by chlorine. In this way may be obtained compounds which have the formulas $CH_2Cl.COOH$, $CHCl_2.COOH$, and $CCl_3.COOH$. They are called chloracetic acid, dichloracetic acid, and trichloracetic acid, respectively. The replacement of hydrogen by chlorine in this case is an example of a general reaction. In order to replace by chlorine a hydrogen atom which is joined directly to carbon, the free halogen is used.

The chlorides of phosphorus replace the hydroxyl group in acetic acid by chlorine. The replacement is an example of a general reaction which has been mentioned in connection with the alcohols. The equation for the reaction (**219**) in the case of phosphorus trichloride is as follows: —

$$3CH_2CO.OH + PCl_3 = 3CH_3CO.Cl + P(OH)_3$$

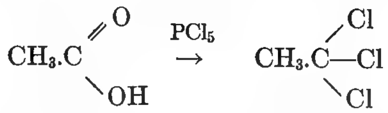
88. Structure of Acetic Acid. — The chemical behavior of acetic acid, which has been described, leads to the structure that has been assigned to it. One hydrogen atom in the molecule differs from the rest of those present in that it can be replaced by metals; $C_2H_4O_2$ when treated with sodium gives $C_2H_3O_2Na$. The reaction between acetic acid and phosphorus trichloride shows that the compound contains a hydroxyl group. When the acid is warmed with phosphorus trichloride one oxygen atom and one hydrogen atom are replaced by one chlorine atom. As the valence of the halogen is one, it is clear that the valence of the group of atoms which it displaced must also be unity. An oxygen and a hydrogen atom combined can show a valence of one only when they are in combination as a hydroxyl group. If the two atoms were united separately to a carbon atom, and were simultaneously replaced by another element, three equivalents would be required to take their place. These facts are shown in the following formulas: —



$$R_3C{-}O{-}H \text{ and } R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}H$$

In the case of the compound represented by the first formula, the combination of the oxygen and hydrogen atoms (hydroxyl group) has a valence of one, and when replaced by chlorine, for example, but one atom of the halogen is required. In the case of the second compound, removal of both oxygen and hydrogen would set free three of the combining powers of carbon, and three atoms of a univalent element would be required to saturate the compound. These facts are discussed at length, as a study of the reactions of oxygen compounds with phosphorus trichloride and similar substances is of great value in the determination of the structure of such compounds.

The considerations given above lead to the conclusion that the formula of acetic acid may be written $C_2H_3O.OH$. The place of the second oxygen atom in the molecule is shown by the fact that acetic acid is converted into a compound of the structure $CH_3.CCl_3$ when heated to a high temperature with phosphorus pentachloride: —



The hydroxyl group is replaced by one chlorine atom, and the doubly-linked oxygen by its equivalent (two atoms) of chlorine. It will be shown later that this second kind of replacement is general in the case of compounds which contain the $C=O$ group. In the case of acids, the doubly-linked oxygen is replaced with difficulty and only at high temperature, but other compounds which contain this group often react readily with phosphorus pentachloride.

An interpretation of the synthesis of acetic acid leads to the same conclusion as to the structure of the acid, as that deduced by its reactions. The synthesis involves the preparation of brommethane from methane and the conversion of the former into methyl cyanide, which on hydrolysis yields acetic acid. As this hydrolysis affects only the CN radical, converting it into the carboxyl group, the conclusion as to the structure of the acid from its synthesis is definite. The steps in the process are represented by the following formulas: —

$$CH_4 \rightarrow CH_3.Br \rightarrow CH_3.CN \rightarrow CH_3.COOH$$

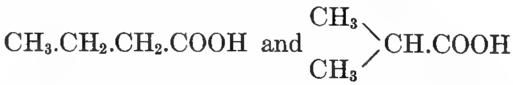
89. Tests for Acetic Acid. — The best way to identify acetic acid is to determine its physical properties — melting-point, boiling-point, odor — and those of a derivative prepared from it, such as the ethyl ester. If, however, only a small amount of the acid to be tested is available, or if it is in solution in water or mixed with other substances, it can be satisfactorily identified. As acetic acid is volatile with steam, it can be freed by distillation from substances non-volatile under these circumstances. The original solution should be acidified with sulphuric acid before distillation in order to set free any acetic acid which may be present in the form of a salt. The distillate is neutralized with sodium hydroxide and evaporated to dryness. A part of the residue is treated with a few drops of concentrated sulphuric acid and gently heated. If acetic acid is present it can be recognized by its characteristic odor. A second portion of the residue is mixed with a few drops of alcohol and an equal quantity of concentrated sulphuric acid and warmed. The presence of the acid is confirmed by the odor of ethyl acetate which is readily recognized.

Higher Fatty Acids

90. The known fatty acids form a complete homologous series up to the compound which contains twenty carbon atoms. The acid in this series containing the largest number of carbon atoms has the formula $C_{33}H_{67}.COOH$. The acids may be considered as derivatives of the paraffin hydrocarbons in which a hydrogen atom is replaced by a carboxyl group. We have already learned that the replacement of hydrogen in hydrocarbons by elements or groups leads to the formation of isomeric compounds. The existence of isomeric fatty acids is a confirmation of the correctness of the view of the structure of organic compounds which has already been developed. It will be recalled that propane yields two substitution-products. The formulas of the two propyl bromides are —

$$CH_3.CH_2.CH_2Br \text{ and } CH_3.CHBr.CH_3$$

The replacement of the halogen atom in these compounds by the CN radical, and the subsequent hydrolysis of the nitriles so prepared should yield acids of the structure



$$CH_3.CH_2.CH_2.COOH \text{ and } \begin{matrix}CH_3\diagdown \\ CH_3\diagup\end{matrix}CH.COOH$$

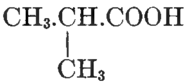
Two fatty acids each of which contains four carbon atoms are known. Their synthesis and reactions are in accord with the view that they have the structure represented by the formulas given above. The acid in which the carbon atoms are in a straight chain is called butyric acid; the isomeric acid is known as isobutyric acid. The opportunity for isomerism among the acids is as great as in the case of the alcohols, but only a small number of the possible isomers have been prepared. A table of a few of the normal acids — those in which the carbon atoms are united in a straight chain — follows: —

NORMAL FATTY ACIDS

Name	Radical in combination with COOH group	Melting-point	Boiling-point	Specific Gravity
Formic acid	H	8.3°	101°	1.2310 (10°)
Acetic acid	CH_3	16.598°	118°	1.0515 (15°)
Propionic acid	C_2H_5	—36°	141°	0.9985 (14°)
Butyric acid	C_3H_7	— 2°	163°	0.9599 (19.1°)
Valeric acid	C_4H_9	—58.5°	186°	0.9560 (0°)
Caproic acid	C_5H_{11}	— 1.5°	205°	0.9450 (0°)
Heptylic acid	C_6H_{13}	—10.5°	223°	0.9186 (17.2°)
Caprylic acid	C_7H_{15}	16.5°	237.5°	0.9100 (20°)
Nonylic acid	C_8H_{17}	12.5°	254°	0.9110 (m.p.)
Capric acid	C_9H_{19}	31.4°	269°	—
—	—	—	—	—
Palmitic acid	$C_{15}H_{31}$	62.618°	271° (100 mm.)	0.8527 (m.p.)
Margaric acid	$C_{16}H_{33}$	60°	—	—
Stearic acid	$C_{17}H_{35}$	69.32°	291° (100 mm.)	0.8454 (m.p.)

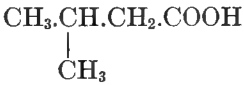
It will be seen from the table that the acids up to capric acid, which contains ten carbon atoms, are liquids at ordinary temperatures. The higher members in the series are waxy solids, which boil without decomposition only under reduced pressure. An interesting fact which has not been explained is that while the boiling-points of the acids increase with a fair degree of regularity as the number of carbon atoms increases, the melting-points show a peculiar irregularity. The melting-points of the acids which contain an even number of carbon atoms are higher than those of the acids containing an odd number of carbon atoms, and which immediately precede or follow them in the series. The solubility in water of the acids, and their volatility with steam, decrease with the number of carbon atoms in the molecule. This difference in solubility and volatility of the acids is the basis of two important analytical methods which are used in the examination of fats. The lower members in the series have characteristic odors, those containing from four to nine carbon atoms having a disagreeable smell, resembling that of rancid butter. The fatty acids are weak acids, that is, they are but slightly ionized in solution.

91. Nomenclature of the Fatty Acids. — The acids in this series are sometimes named according to a system which was developed in an endeavor to simplify the nomenclature of organic compounds. In naming an acid the final *e* of the hydrocarbon which contains the same number of carbon atoms as the acid, is replaced by the termination *oic*. Thus acetic acid, $C_2H_4O_2$, is called ethanoic acid as it contains the same number of carbon atoms as ethane, C_2H_6. The method of naming isomers will be clear from the following examples: —



$$CH_3.\underset{\overset{|}{CH_3}}{CH}.COOH$$

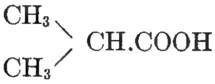
2-methyl-propanoic acid



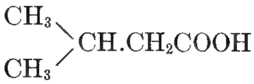
$$CH_3.\underset{\overset{|}{CH_3}}{CH}.CH_2.COOH$$

3-methyl-butanoic acid

An older systematic nomenclature is often used. In this the acids are considered as substitution-products of acetic acid. The acid of the structure



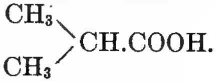
is called, for example, dimethyl-acetic acid;



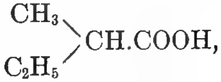
is isopropyl-acetic acid.

A few of the more important fatty acids will be described briefly.

92. Propionic Acid, $C_2H_5.COOH$. — This acid occurs in small quantities in pryoligneous acid. It can be prepared by the application of the general synthetical methods described under acetic acid. It resembles the latter in chemical properties. When propionic acid is treated with chlorine, substitution takes place, the compound formed having the structure $CH_3.CHCl.COOH$. This is called α-chlorpropionic acid to distinguish it from an isomer, called β-chlorpropionic acid, in which the halogen atom is united to the end carbon atom of the chain, $CH_2Cl.CH_2.COOH$. In naming substitution-products of the fatty acids there is prefixed to the name a Greek letter which serves to indicate the carbon atom with which the substituent is in combination. The first, second, third, fourth, etc., carbon atom from the carboxyl group are designated by α, β, γ, δ, etc., respectively.

93. Butyric Acids, $C_3H_7.COOH$. — Two acids of the formula $C_4H_8O_2$ are known. In normal butyric acid the propyl radical is in combination with the carboxyl group, $CH_3CH_2CH_2.COOH$: isobutyric acid contains the isopropyl radical,  $\begin{matrix} CH_3 \searrow \\ CH_3 \nearrow \end{matrix} CH.COOH.$ The structures of the acids are derived from their syntheses from propyl bromide and isopropyl bromide, respectively. Normal butyric acid occurs in combination with glycerol in butter (whence the name of the acid), and in other fats. It is formed as the result of the fermentation of sugars, fats, and other substances, and is found in the free state in rancid butter, Limburger cheese, and sweat. It has a characteristic, disagreeable odor. It can be prepared by the general synthetic methods which have been described. A micro-organism which appears to be present in Limburger cheese has the power to convert lactic acid, the chief acid constituent of sour milk, into butyric acid. The acid is conveniently prepared in this way.

Butyric acid is a thick, sour liquid, which boils at 163°, and is miscible with water in all proportions. Addition of calcium chloride to an aqueous solution of the acid causes the latter to separate as an oil. The other soluble fatty acids, with the exception of formic and acetic acids, act in this way. The salts of butyric acid are soluble in water. Calcium butyrate, $(C_4H_7O_2)_2Ca.H_2O$, is more soluble in cold than in hot water. It is precipitated, in part, when a cold saturated solution of the acid is heated to boiling. The calcium salt of isobutyric acid $(C_4H_7O_2)_2Ca.5H_2O$, is more soluble in hot than in cold water.

94. Valeric Acids, $C_4H_9.COOH$. — The four possible acids of the formula $C_5H_{10}O_2$ are known. Isovaleric acid, $(CH_3)_2CH.CH_2COOH$, and active valeric acid,  $\begin{matrix} CH_3 \searrow \\ C_2H_5 \nearrow \end{matrix} CH.COOH,$ occur in nature. They are found in the plant all-heal or valerian, and in angelica root. A mixture of these acids may be prepared by oxidizing commercial amyl alcohol with chromic acid.

95. Palmitic Acid, $C_{15}H_{31}.COOH$, and **Stearic Acid**, $C_{17}H_{35}.COOH$, occur as glycerol esters in most animal and vegetable fats and oils. They are prepared from these sources in large quantities for the manufacture of stearin candles, tallow and palm oil being chiefly used. The hydrolysis of the fat is usually accomplished by boiling with milk of lime, either in an open vessel or under a pressure of from 8 to 10 atmospheres. The insoluble calcium salts of the acids so formed are treated with sulphuric acid, when the free fatty acids rise to the surface of the hot solution in the form of an oil. This is allowed to stand for a few days at a temperature of about 30° in order to bring about the crystallization of the palmitic and stearic acids. The oleic acid — an unsaturated acid of the formula $C_{17}H_{33}.COOH$ — which is present in the mixture in the form of an oil, is removed by hydraulic pressure. The resulting solid mixture of stearic and palmitic acids is known in the trade as "stearin." This use of the word should not be confounded with its ordinary use in organic chemistry; palmitin and stearin are the names given to the glycerol esters of palmitic and stearic acids, respectively. The yield of "stearin" from tallow or palm oil varies from 44 to 48 per cent of the weight of the fat. The "stearin" is finally mixed with a small amount of paraffin wax to prevent crystallization, and moulded into candles. Candles are also made from tallow, paraffin, ozokerite, and spermaceti.

Palmitic acid and stearic acid are colorless, wax-like substances, which melt at 63° and 69°, respectively. They are insoluble in water, but dissolve in organic solvents. The sodium and potassium salts of the acids are soluble in water, while those of calcium, magnesium, and the heavy metals are insoluble. Both acids have the normal structure, that is, the alkyl radicals which they contain, $C_{15}H_{31}$, and $C_{17}H_{35}$, respectively, consist of carbon atoms united in a straight chain.

96. Soaps. — Most fats and oils consist of mixtures of glycerides, which are substances which yield glycerol and fatty acids when hydrolyzed. If the hydrolysis is effected by treating the esters with a base, a mixture of the corresponding salts of the acids is obtained. These mixtures are known as soaps. The decomposition of stearin by sodium hydroxide is represented by the following equation, which is typical of the reaction that takes place in the case of the other esters present in fats and oils: —

$$(C_{17}H_{35}COO)_3C_3H_5 + 3NaOH = 3C_{17}H_{35}COONa + C_3H_5(OH)_3.$$

The decomposition by which a fat is converted into a soap, is called *saponification*. The word is frequently applied to the analogous change which esters other than fats undergo with bases, although the salts formed are not soaps. It is sometimes used as synonymous with hydrolysis.

Sodium hydroxide and potassium hydroxide are generally employed in soap-making. The mixture of glycerol and potassium salts obtained when the latter is used, is known as a *soft soap*, on account of the fact that it is a deliquescent thick liquid, or jelly-like mass. Soft soaps are also prepared by adding a large quantity of water to a sodium soap. The materials used in soap-making vary with the quality of the soap desired. White soaps are usually made from tallow, palm oil, or cocoanut oil, and common laundry soaps from tallow, bone grease, or cotton-seed oil. Rosin is often mixed with the fat in the preparation of the laundry soaps, as it is cheap and yields a soap which lathers freely. Olive oil is used in the manufacture of Castile soap. The so-called "olein soaps" are prepared from the oleic acid obtained as a by-product in the manufacture of stearin candles.

In the preparation of soap by the "cold process" the fat is treated with a strong aqueous solution of the exact amount of alkali required to saponify it. The mixture is well stirred, and heated a few minutes until reaction begins. The heat generated by the saponification is sufficient to carry it on after it is once started. At the end of several days the reaction is complete. Soap prepared in this way contains all the glycerin formed and any excess of fat or alkali which may result from incomplete saponification or the incorrect mixing of the substances used. It is apt to turn yellow and become rancid.

Soaps are usually made by boiling the fat with a solution of sodium hydroxide. After saponification is complete, sodium chloride is added to precipitate the soap which is in solution, and the mixture is allowed to cool. The lye, which contains most of the glycerol, is now drawn off, a small amount of water is added, and the soap is boiled until it loses its granular appearance. When cold, it is mixed with a perfume, or, in the case of some scouring soaps, with sodium silicate, sodium carbonate, borax, sand, etc., and cut into the desired shape. Soaps are colored by adding to them small amounts of copperas, ultramarine, or other pigment. *Transparent soaps* are made by dissolving a common soap in alcohol and distilling off the latter from the decanted solution until the residue is obtained as a clear transparent jelly, which is finally carefully dried in moulds. The addition of glycerol and alcohol or a solution of cane sugar to cold-process soaps, renders them more or less transparent.

Hard soaps consist essentially of the sodium salts of palmitic, stearic, and oleic acids. As the calcium and magnesium salts of these acids are insoluble in water, soap does not immediately pass into solution and form a lather with "hard water." The soap dissolved reacts with the metallic salts in solution and the corresponding salts of the fatty acids are precipitated. This process continues until all the metals which form insoluble soaps are precipitated. The reaction which takes place is illustrated by that between sodium palmitate and calcium chloride: —

$$2C_{15}H_{31}.COONa + CaCl_2 = (C_{15}H_{31}.COO)_2Ca + 2NaCl.$$

The amount of a solution of soap of definite concentration which must be added to a definite volume of water before the mixture produces a lather on shaking, is taken as a measure of the hardness of water in water analysis.

The cleansing action of soap is due to two causes. When dissolved in water soap undergoes slight hydrolysis like the salts of other weak acids: —

$$C_{17}H_{35}.COONa + H_2O = C_{17}H_{35}.COOH + NaOH.$$

The alkali produced saponifies a part of the grease with which the dirt to be removed is usually mixed. As the sodium hydroxide is removed in this way, more soap is hydrolyzed and a constant supply of the base is automatically furnished. The extent of hydrolysis of soap increases with rise in temperature. For this reason a hot solution contains more free alkali than a cold one. The cloudy appearance of a hot soap solution is due to the presence of minute globules of the fatty acids set free. This is shown by the fact that the free acids may be removed from such a solution by extracting it with a liquid in which the acids are soluble. The efficiency of a soap as a cleansing agent is largely due, however, to the fact that it emulsifies oils, that is, it converts them into such a finely divided condition that they remain suspended in water and can, therefore, be readily removed. Mineral oils, which can not be saponified, can thus often be removed from the skin or from fabrics by means of soap.

97. Properties of Acids of Analytical Significance. — The identification of the acids of this series is not difficult when an individual in the pure state is to be identified. In general, however, the acids are found mixed with other substances and their separation in a pure condition is difficult. The physical properties of the acids, which have been described at some length, are helpful in their determination. The odor and solubility of the lower members of the series, the fact that calcium chloride precipitates most of the soluble acids, and the waxy appearance of the higher members should be noted. Being saturated compounds they do not readily react the halogens. They dissolve in sodium hydroxide and sodium carbonate. The salts of the higher acids are hydrolyzed by water. The sodium salts of the higher acids are soaps and show the characteristic lathering when agitated with water.

UNSATURATED MONOBASIC ACIDS

98. A number of acids are known which stand in the same relation to the unsaturated hydrocarbons as do the fatty acids to the paraffins. Some of these acids occur in nature in the free condition or in the form of esters, and others have been synthesized in the laboratory. Those which occur in nature have names that recall the names of the substances from which they were first prepared; crotonic acid, for example, was isolated from croton oil.

In the systematic nomenclature of organic compounds the acids of this series are named from the hydrocarbons to which they are related, in a way analogous to that adopted for the fatty acids. For example, acrylic acid, $CH_2{=}CH.COOH$, is named propenoic acid. The position of the double bond is indicated by placing before the name of the acid the Greek letter Δ to which is added a number indicative of the position of the double bond, thus, the substance of the structure, $CH_3.CH_2.CH{=}CHCH_2COOH$ is called Δ^2–hexenoic acid. The ^{2} after the Δ indicates that the double bond is between the second and third carbon atom from the carboxyl group. The older names of the acids are usually used; in the case, however, of newly described acids, and those of complex structure, the systematic method of naming compounds is employed.

It will be recalled that a double bond can be established in a compound by the removal of a molecule of halogen hydride (HCl, HBr, or HI) or two halogen atoms from a halogen derivative of a saturated hydrocarbon, and by the elimination of water from an alcohol. The substitution-products of the fatty acids undergo analogous changes when subjected to the action of the proper reagents. The presence of the carboxyl group modifies, to some extent, the ease with which a double or triple bond is established, but the course of the reaction is the same as in the case of the simple substitution-products of the hydrocarbons.

99. Acrylic Acid, $CH_2{=}CH.COOH$. — The synthesis of unsaturated acids may be illustrated by the methods which can be used to prepare acrylic acid — the first member of the series of acids which contain one double bond. Acrylic acid is formed when β-iodopropionic acid is warmed with an alcoholic solution of potassium hydroxide: —

$$CH_2I.CH_2.COOH + 2KOH = CH_2{:}CH.COOK + KI + H_2O$$

The acid formed reacts with a part of the alkali present and is obtained as the potassium salt. It has been found in this and other cases that a halogen atom in the β-position to the carboxyl group is readily removed in this way. α,β-Dibrompropionic acid is converted into acrylic acid when treated with zinc in the presence of dilute sulphuric acid: —

$$CH_2Br.CHBr.COOH + Zn = CH_2{:}CH.COOH + ZnBr_2$$

The preparation of an unsaturated acid by bringing about the elimination of water from a saturated compound is illustrated by the preparation of acrylic acid from the hydroxyl derivatives of propionic acid. When β-hydroxypropionic acid is distilled, decomposition takes place and acrylic acid is formed: —

$$CH_2OH.CH_2.COOH = CH_2{:}CH.COOH + H_2O$$

If the unsaturated acid is not formed as the result of heat alone, the acid is warmed with a dehydrating agent, or a salt of it is heated. Thus, when the sodium salt of lactic acid is heated, the sodium salt of acrylic acid is formed: —

$$CH_3.CHOH.COONa = CH_2{:}CH.COONa + H_2O$$

The student should study the above reactions in the light of a knowledge of the methods used to prepare unsaturated hydrocarbons. A review of these methods (**29**) at this time will serve to make the knowledge of these important reactions more definite, and will do away with the necessity of learning as isolated facts the ways by which acrylic acid may be prepared. The general synthetic methods which have been given so far, and many others to be described later, are used repeatedly in the preparation of organic compounds. Each new fact should be associated, as far as possible, with facts already learned. It is only in this way that the mass of material treated in organic chemistry can be mastered, and the relationships which exist in the science can be appreciated.

Acrylic acid can not be prepared, as might be expected, by the following transformations, which are analogous to those made use of in the preparation of acetic acid: —

$$CH_2{:}CH.Br \rightarrow CH_2{:}CH.CN \rightarrow CH_2{:}CH.COOH$$

The conversion of bromethylene into the corresponding cyanide can not be effected. The fact will be emphasized later that halogen atoms united to a doubly-linked carbon atom, as in this case, do not, in general, undergo direct replacement by other groups in the way which is characteristic of halogen atoms in saturated compounds.

Acrylic acid may be prepared by two methods analogous to those used in the preparation of fatty acids. Allyl alcohol or acrolein, the corresponding aldehyde, are converted into acrylic acid by oxidation: —

$$CH_2{:}CH.CH_2OH + 2O = CH_2{:}CH.COOH + H_2O$$
$$CH_2{:}CH.CHO + O = CH_2{:}CH.COOH$$

Acrylic acid is a liquid which has a pungent odor resembling somewhat that of acetic acid. It is miscible with water in all proportions, melts at 8°, boils at 140°, and has the specific gravity 1.062 at $\frac{16°}{4°}$. It is a stronger acid than acetic acid and forms well characterized salts and esters. The fact that it contains a double bond is shown by its behavior with other substances. It can be reduced to propionic acid by nascent hydrogen: —

$$CH_2{:}CH.COOH + 2H = CH_3.CH_2.COOH$$

It unites directly with chlorine and bromine: —

$$CH_2{:}CH.COOH + Br_2 = CH_2Br.CHBr.COOH$$

The halogen acids add to acrylic acid at the double bond, forming β-substitution-products of propionic acid: —

$$CH_2{:}CH.COOH + HI = CH_2I.CH_2.COOH$$

In the addition, the negative halogen atom unites with the more positive end carbon atom. The presence of the carboxyl group in combination with the α-carbon atom renders the latter more or less negative as compared with the carbon atom in the CH_2 group. Addition to unsaturated compounds takes place, in general, in this way. The negative part of the molecule which unites with the unsaturated compound enters into combination with the more positive of the carbon atoms. Hydrogen and alkyl groups are positive; oxygen, hydroxyl, halogen, and carboxyl groups are negative. The presence of these groups in combination with a carbon atom, affects the properties of the latter in relation to its positive or negative nature.

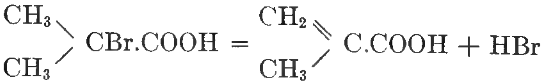
Like the unsaturated hydrocarbons, acrylic acid is oxidized by a cold, dilute, neutral solution of potassium permanganate. The oxidation takes place at the double bond.

The various syntheses of acrylic acid and the chemical reactions which it undergoes with bases, halogens, halogen acids, etc., have led to the view that the structure of its molecule is represented by the formula which has been assigned to it. The student should endeavor to understand clearly how these syntheses and reactions lead to the accepted conclusion.

100. Crotonic Acids, $C_3H_5.COOH$. — Three unsaturated acids of the formula $C_3H_5.COOH$ should be capable of existence according to the structure theory. These are, —

(1) $CH_2=C.CH_3.COOH$
(2) $CH_3.CH=CH.COOH$
(3) $CH_2=CH.CH_2COOH$

The first of these acids may be considered as derived from acrylic acid, $CH_2=CH.COOH$, by the replacement of a hydrogen atom joined to the α-carbon atom by a methyl group. It is called methyl acrylic acid. The acid may be prepared by treating bromisobutyric acid with alcoholic potash: —



$$\left.\begin{matrix}CH_3\\CH_3\end{matrix}\right\rangle CBr.COOH = \left.\begin{matrix}CH_2\\CH_3\end{matrix}\right\rangle C.COOH + HBr$$

The structure of the acid is deduced from this synthesis and from its chemical reactions.

The acid corresponding to the second formula, in which the methyl group is in combination with the β-carbon atom, is called crotonic acid. The third is vinyl acetic acid which has been prepared from allyl bromide by Grignard's method: —

$$\begin{aligned}&CH_2{:}CH.CH_2Br + Mg = CH_2{:}CH.CH_2MgBr\\&CH_2{:}CH.CH_2MgBr + CO_2 = CH_2{:}CH.CH_2CO_2MgBr\\&CH_2{:}CH.CH_2CO_2MgBr + H_2O = CH_2{:}CH.CH_2COOH +\\&\qquad\qquad\qquad Mg.Br.OH.\end{aligned}$$

The interest in these compounds centers in crotonic acid, as an acid is known, isomeric with crotonic acid, which differs markedly from it in physical properties, but appears to have, as a result of the study of its chemical properties, a structure which is best represented by that given to crotonic acid. As the three formulas given above are the only ones possible for acids containing a double bond and having the composition $C_3H_5.COOH$, and as four well characterized substances of this composition are known which show the kind of unsaturation represented graphically by the so-called doubly-linked carbon atoms, an extension of the structure theory as developed so far is necessary. Isomerism similar to that shown by crotonic and isocrotonic acids, has been observed in many compounds which contain double bonds.

The theory put forward to explain these facts by van't Hoff is an extension of the conception of the space relations of the atoms in the molecule, which has proven so valuable in the study of the isomerism which exists among optically active compounds (**63**).

The spacial formula of a compound in which two carbon atoms are joined by a single bond is represented by figure 4. Figures 5 and 6 represent compounds that contain a double bond.

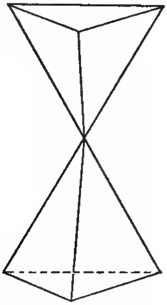


FIGURE 4

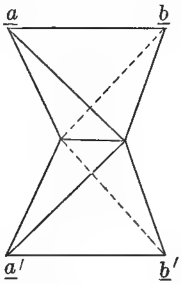


FIGURE 5

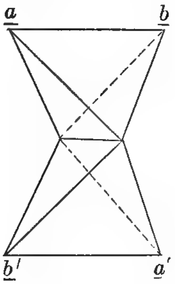
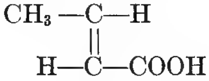
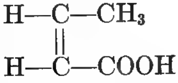


FIGURE 6

An examination of figures 5 and 6 shows that isomerism may exist when the atoms or groups at *a* and *a′* are different from those at *b* and *b′*. In one case, figure 5, *a* and *a′* are on the same side of the molecule; in the other case, figure 6, they are on opposite sides. The space relations are usually represented on a plane surface by simple graphic formulas without the use of the tetrahedra, in the following manner: —

(1) 

$$\begin{array}{c} CH_3—C—H \\ \| \\ H—C—COOH \end{array}$$

(2) 

$$\begin{array}{c} H—C—CH_3 \\ \| \\ H—C—COOH \end{array}$$

The compound in which the radicals are on the same side of the molecule are designated by prefixing to the name of the compound the syllable *cis*, which means "on this side." The prefix *trans*, meaning "across," is used in naming the isomer. Formula 1 above is transcrotonic acid, formula 2 ciscrotonic acid. The acids are said to be *stereoisomers*.

Crotonic Acid (Δ^1-*cis*-butenoic acid) occurs in croton oil. It is a crystalline, colorless solid, which melts at 72° and boils at 185°. It can be prepared from α- or β-brombutyric acid or from β-hydroxybutyric acid.

Isocrotonic Acid (Δ^1-*trans*-butenoic acid) is prepared by reactions which can not be discussed with profit at this point on account of their complexity. It melts at 15.5° and boils at 172°. Crotonic acid is transformed into normal butyric acid when reduced by nascent hydrogen. This fact indicates that the carbon atoms in the compound are arranged in a straight chain: —

$$CH_3CH{:}CH.COOH + 2H = CH_3CH_2CH_2.COOH$$

Isocrotonic acid can also be converted into the same acid. Both acids yield β-iodobutyric acid when treated with hydriodic acid.

101. Oleic Acid, $C_{17}H_{33}.COOH$, occurs abundantly in nature in combination with glycerol in many fats and oils. Glyceryl trioleate, $(C_{17}H_{33}COO)_3C_3H_5$, is the chief constituent of the fatty oils, such as olive oil and whale oil, and of the fats of cold-blooded animals. It is the liquid constituent of tallow and other animal fats. It is obtained as a by-product in the preparation of stearin candles (**95**), and is used in the manufacture of soap. The acid may be separated from palmitic, stearic, and other acids with which it occurs, by taking advantage of the fact that lead oleate is soluble in ether, in which the lead salts of the other acids are insoluble. Oleic acid is obtained from its lead salt by treatment with an acid. It is an oily, odorless liquid, which is insoluble in water. It solidifies when cooled and forms crystals which melt at 14°.

The presence of a double bond in oleic acid is shown by the fact that one gram-molecule of the acid unites with one gram-molecule of bromine; dibromstearic acid is formed: —

$$C_{17}H_{33}COOH + Br_2 = C_{17}H_{33}Br_2.COOH$$

As nascent hydrogen converts oleic acid into stearic acid, the carbon atoms are arranged in a straight chain. The position of the double bond is indicated by the composition of the products obtained as the result of oxidation: —

$$\underset{\text{oleic acid}}{CH_3(CH_2)_7CH{:}CH(CH_2)_7COOH} + 4O = \underset{\text{pelargonic acid}}{CH_3(CH_2)_7COOH} + \underset{\text{azelaic acid}}{COOH(CH_2)_7COOH}$$

Thus, oleic acid which contains eighteen carbon atoms is converted by oxidation into two acids, each of which contains nine carbon atoms. As unsaturated compounds usually break at the double bond when subjected to active oxidation, the reaction given above is taken as evidence that in oleic acid this bond is situated as indicated by the structural formula given. In the oxidation the unsaturated carbon atoms are converted into carboxyl groups; a monobasic acid and a dibasic acid, which contains two carboxyl groups, are thus obtained. Oleic acid, like other unsaturated compounds, reduces a dilute aqueous solution of potassium permanganate; dihyoxystearic acid is formed: —

$$CH_3(CH_2)_7CH{:}CH(CH_2)_7COOH + 2O =$$
$$CH_3(CH_2)_7CHOH.CHOH(CH_2)_7COOH$$

Oleic acid undergoes an interesting transformation when treated with a small quantity of nitrous anhydride. In a few minutes it is converted into a solid substance, which appears from its reactions to have a structure identical with that given above for oleic acid. The compound formed, called *elaidic acid,* is considered to be a stereoisomer of oleic acid, the relation between the two being similar to that between crotonic and isocrotonic acids. The glycerol ester of oleic acid undergoes a similar change, and is converted into a solid called *elaidin.* This reaction is frequently used in the examination of oils which contain olein. The consistency of the mass after treatment of the oil with a small amount of nitric acid in which mercury or copper has been dissolved, gives some indication of the relative amount of olein in the oil; thus, a hard mass is given by almond, lard, and certain other oils; mustard oil yields a product of the consistency of butter; and a pasty mass which separates from a fluid portion is obtained from cottonseed, sunflower, and sesame oils. The test is known as the *elaidin test.* It is valuable only when used along with other analytical methods.

Acids with Two Double Bonds

102. Sorbic Acid, C_5H_7COOH, is an example of acids of this class, very few of which are known. It is present in the unripe berries of the mountain-ash. The structure of the acid has been proved by its synthesis and its reactions to be that represented by the formula $CH_3.CH=CH.CH=CH.COOH$. It adds four atoms of bromine or two molecules of hydrobromic acid, and is thereby converted into substitution-products of caproic acid, which is a member of the series of saturated acids.

103. Linoleic Acid, $C_{17}H_{31}.COOH$, an important acid which contains two double bonds, occurs as the glycerol ester in linseed, cottonseed, sunflower, and other oils. The property possessed by linseed and other so-called drying oils of hardening when exposed to the air is due to the fact that the esters of linoleic and similar unsaturated acids absorb oxygen and are thereby converted into solid substances. Such oils are extensively used as a constituent of varnishes and oil paints.

The oxidation of linseed oil, which takes place in "drying," is attended by the generation of much heat. If the oil is exposed in thin layers on porous inflammable material, such as cotton rags or waste, spontaneous combustion may take place as the result of active oxidation. Linseed oil dries more rapidly when exposed to the air if it has been previously "boiled" for some hours. The process consists in heating the oil with certain oxides or salts, called "driers," such as litharge, lead acetate, or borate of manganese, which probably act as catalytic agents in the addition of oxygen to the unsaturated esters. Very little of the drier is dissolved by the oil. Raw linseed oil is used as a soap stock for soft soap, in some kinds of paints, and in the making of varnish and rubber substitutes. Boiled oil is used in paints and in the manufacture of oil cloth and printing-ink. Linoleum is made from a mixture of ground cork and boiled linseed oil which has been exposed to the air until oxidized to a translucent jelly.

Linseed oil contains, in addition to the glycerol ester of linoleic acid, the esters of the more highly unsaturated acids, linolenic and isolinolenic acids, both of which have the composition $C_{17}H_{29}.COOH$. The structure of these acids has not been definitely determined.

Acids with One Triple Bond

104. Propiolic Acid, $HC{\equiv}C.COOH$, is a liquid with a pungent odor resembling that of acetic acid. After freezing it melts at 6°. It can be distilled without decomposition only under diminished pressure. It is interesting on account of the fact that its reactions show clearly its relation to acetylene. It forms as an acid, well characterized salts, and as a triple bonded compound, metallic derivatives, which result from the replacement of the hydrogen atom joined to carbon by silver or copper. When the acid is treated with an ammoniacal solution of silver nitrate a colorless, crystalline salt is formed, which soon turns yellow and explodes when struck. Propiolic acid may be prepared by the action of carbon dioxide on the sodium derivative of acetylene: —

$$HC{\equiv}CNa + CO_2 = HC{\equiv}C.COONa$$

The free acid is obtained from the salt by treatment with an acid.

PROBLEMS

1. Make a summary, by writing equations, (*a*) of the general reactions used in the preparation of acids, and (*b*) of the chemical properties of acids.

2. By what reactions may (*a*) a hydrogen atom be replaced by a chlorine atom, (*b*) H by OH, (*c*) H by I, (*d*) Br by CN, (*e*) Br by COOH, (*f*) H by COOH, (*g*) OH by H, (*i*) COOH by H, and (*j*) CO by CBr_2?

3. Write equations for reactions by which (*a*) acetic acid may be converted into propionic acid and (*b*) methyl alcohol into acetic acid.

4. Write the graphic formulas of the isomeric acids of the formula $C_5H_{11}.COOH$, and name each according to the two systems described in section **91**.

5. Write an equation for a reaction which takes place when a soap solution is added to (*a*) a hard water which contains calcium sulphate and (*b*) a solution of sulphuric acid.

6. Devise a method by which the "hardness" of water could be determined quantitatively by the use of a solution of soap.

7. Write equations for the reactions involved in the preparation of an acid of the formula $CH_2=CH.CH_2COOH$ from propyl alcohol.

8. Write the graphic formula of the compound formed when acrylic acid is treated with a cold aqueous solution of potassium permanganate.

9. Name the compounds formed by the action of bromine and of hydrobromic acid on crotonic acid.

CHAPTER VIII

POLYBASIC ACIDS

105. The acids which have been described so far are monobasic acids as they contain only one carboxyl group, and, therefore, but one hydrogen atom which undergoes ionization and can be replaced by metals. A number of acids of importance are known which contain two or more of these groups and, consequently, resemble the inorganic acids like sulphuric acid and phosphoric acid in their ability to form acid salts.

The saturated dibasic acids fall into an homologous series having the general formula $C_nH_{2n-2}O_4$. The following table gives a list of some of the dibasic acids which contain the carbon atoms in a straight chain: —

DIBASIC ACIDS, $C_nH_{2n-2}O_4$

Name	Formula	Melting-point	Parts by Weight Soluble in 100 Parts of Water
Oxalic acid	COOH . COOH	189°[1]	10.2 at 20°
Malonic acid	$COOH . CH_2 . COOH$	133°	139.37 at 15°
Succinic acid	$COOH . (CH_2)_2 . COOH$	182°	5.14 at 14.5°
Glutaric acid	$COOH . (CH_2)_3 . COOH$	98°	80.3 at 14°
Adipic acid	$COOH . (CH_2)_4 . COOH$	149°	1.44 at 15°
Pimelic acid	$COOH . (CH_2)_5 . COOH$	105.5°	4.1 at 20°
Suberic acid	$COOH . (CH_2)_6 . COOH$	141°	0.142 at 15.5°

It is seen from an inspection of the melting-points given in the table that the acids which contain an even number of carbon atoms melt at a higher temperature than the acid next in the series which contains an odd number of carbon atoms. This peculiarity, the cause of which is not understood, has already been noted in the case of the saturated monobasic acids. It is also seen that the melting-points of the acids with an even number of carbon atoms decrease with the increase in the number of carbon atoms in the molecule. The solubilities of the acids in water exhibit a similar irregularity. Those containing an uneven number of carbon atoms are much more soluble than those with an even number.

---

[1] Anhydrous oxalic acid.

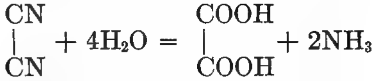
The acids in this series crystallize well, and those which contain more than three carbon atoms can be distilled under diminished pressure without decomposition. When heated at high temperatures under atmospheric pressure water is given off and anhydrides are formed. The dibasic acids are not volatile with steam and, consequently, can be readily separated from the lower fatty acids. The properties and reactions of a few typical members of the series will now be described in more detail.

106. Oxalic Acid, $(COOH)_2$, is one of the longest known organic substances. Its occurrence was first noted at the beginning of the seventeenth century, in the form of the acid potassium salt in sorrel. The acid crystallizes from water in the hydrated form, which contains two molecules of water of crystallization. It begins to lose water at 30°, and at 100° the loss is rapid. The acid sublimes with partial decomposition at 150°–160°, and at a higher temperature is converted into water, carbon dioxide, carbon monoxide, and formic acid. The anhydrous acid is hygroscopic, and is frequently used as a dehydrating agent. It is readily soluble in alcohol, and sparingly soluble in ether. The acid and its salts are poisonous.

Oxalic acid occurs widely distributed in nature, usually in the form of the acid potassium or the calcium salt. Plants of the *oxalis* varieties contain appreciable quantities of the salts of oxalic acid. Rhubarb is especially rich in these salts. When the plant is covered with water it resists decay for a long time. The oxalic acid present is, in all probability, the agent which prevents the growth of the organisms which bring about putrefaction. Calcium oxalate frequently occurs in the urine as a crystalline sediment and in the cell-walls of plants. The ammonium salt is found in guano. The acid is used in dyeing, in calico printing, and in analytical chemistry.

Oxalic acid resists the action of nitric acid and certain other oxidizing agents, and, consequently, is obtained when many complex organic compounds, such as sugars, cellulose, and starch, are subjected to oxidation. The acid can be obtained in a pure condition by gently heating cane sugar with about six times its weight of concentrated nitric acid. It is prepared commercially by heating wood shavings or saw-dust with a strong aqueous solution of potassium and sodium hydroxides at 240°–250°. The product of the reaction is taken up in water; milk of lime is added to precipitate calcium oxalate; and, finally, the latter, after washing, is treated with sulphuric acid, which precipitates the calcium as sulphate and liberates the oxalic acid. A single recrystallization of the acid does not yield a chemically pure product, as the acid obtained in this way contains a small percentage of the difficultly soluble salts of the acid. The pure acid is best obtained by sublimation and subsequent crystallization of the slightly impure compound.

Oxalic acid may be synthesized in the laboratory by methods which are of scientific interest. When an aqueous solution of cyanogen is allowed to stand, ammonium oxalate is formed: —



$$\begin{array}{l}CN\\|\\CN\end{array} + 4H_2O = \begin{array}{l}COOH\\|\\COOH\end{array} + 2NH_3$$

$$(COOH)_2 + 2NH_3 = (COONH_4)_2$$

This reaction recalls the preparation of acetic acid from methyl cyanide: —

$$CH_3CN + 2H_2O = CH_3COOH + NH_3$$

In both cases the CN radical is converted into the carboxyl group. When the alkali formates are heated away from air at about 400° a good yield of an oxalate is obtained: —

$$2H.COONa = H_2 + (COONa)_2$$

Oxalic acid undergoes a number of important decompositions. When heated with a dehydrating agent it is converted into carbon dioxide and carbon monoxide; sulphuric acid is usually used to effect the decomposition: —

$$(COOH)_2 + H_2SO_4 = CO + CO_2 + H_2SO_4.H_2O$$

It has been mentioned above that heat alone brings about a partial decomposition of oxalic acid in this way. In the presence of uranium salts, which act as a catalytic agent, the decomposition of an aqueous solution of an oxalate into carbon monoxide and carbon dioxide takes place rapidly in the sunlight. It will be recalled that when heated with glycerol the products are carbon dioxide and formic acid, and that the acid is used in the preparation of allyl alcohol from glycerol (**80**).

Oxalic acid is readily oxidized by potassium permanganate, manganese dioxide, chromic acid, and other active oxidizing agents. It precipitates gold from its solution. The oxidation proceeds quantitatively according to the equation: —

$$(COOH)_2 + O = 2CO_2 + H_2O$$

As the acid can be obtained in the pure condition it, or one of its salts, is used to standardize solutions of potassium permanganate to be used in volumetric analysis. The complete reaction is expressed by the equation: —

$$5(COOH)_2 + 2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 \\ +10CO_2 + 8H_2O$$

Two molecules of potassium permanganate in the acid solution furnish five active oxygen atoms, which convert five molecules of oxalic acid into carbon dioxide and water. The rate of the oxidation of oxalic acid by potassium permanganate is markedly accelerated by the presence of manganous sulphate. At first the reaction proceeds slowly, but after a few drops of the solution of potassium permanganate have reacted the decolorization takes place instantly.

Oxalic acid is one of the strongest of the organic acids, as it is highly ionized in aqueous solution. Its relation to other acids in this respect will be discussed at length later (**278**).

107. Oxalic acid shows many of the reactions which are characteristic of compounds containing the carboxyl group. It forms esters and other compounds. Its reactions with the halides of phosphorus, however, are abnormal. An acid chloride, which in the case of oxalic acid should have the formula $(CO.Cl)_2$, is not formed when the acid is treated with phosphorus pentachloride. The latter acts in this case as a dehydrating agent, the products formed being, as with sulphuric acid, carbon dioxide and carbon monoxide. The water withdrawn from the acid reacts with the phosphorus pentachloride to form phosphorus oxychloride and hydrochloric acid: —

$$(COOH)_2 + PCl_5 = CO_2 + CO + POCl_3 + 2HCl$$

The structure assigned to oxalic acid is deduced from the fact that it is a dibasic acid. The conclusion is in accord with the formation of the acid as the result of the oxidation of glycol — a compound which is known to consist of two primary alcohol groups in combination with each other.

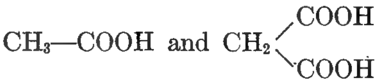
108. A number of the oxalates are of importance and of interest. All are insoluble in water except those which contain the alkali metals or ammonium. Neutral *potassium oxalate,* $K_2C_2O_4 . H_2O$, dissolves in three parts of water at 16°. *Acid potassium oxalate,* KHC_2O_4, is much less soluble, 26 parts of water at 8° being necessary for its solution. The acid salt forms a compound with oxalic acid, which has the formula $KHC_2O_4 . H_2C_2O_4 . 2H_2O$. It is called *potassium tetroxalate* or potassium quadroxalate, and as it can be readily obtained in a pure condition it is sometimes used in preparing standard solutions of alkalies and of potassium permanganate. The salt is sold under the name of "salt of sorrel," and is used to remove iron rust and ink stains from fabrics. The iron is converted by the salt into potassium ferrous oxalate, which is a yellow salt, soluble in water. In the case of an iron ink a similar reaction takes place. As many aniline dyes which are unaffected by oxalic acid are now used for inks, bleaching powder or other active oxidizing agents are often more efficient than oxalic acid in removing ink stains. *Calcium oxalate,* $CaC_2O_4 . 2H_2O$, is insoluble in water and acetic acid, but dissolves readily in mineral acids. It is precipitated when a soluble calcium salt is added to a neutral or an ammoniacal solution of an oxalate. The formation of the salt in this way, and its action with acetic acid and mineral acids, is often used as a *test for oxalic acid* and for calcium. A confirmatory test for oxalic acid is to heat the acid or its salt with concentrated sulphuric acid and ignite the carbon monoxide formed, which burns with a characteristic blue flame. As magnesium oxalate is insoluble in water and soluble in acetic acid, oxalic acid may be used to separate magnesium from calcium.

A number of double oxalates are known. *Potassium ferrous oxalate,* $K_2Fe(C_2O_4)_2$, is an active reducing agent, which is used as a developer for photographic plates. *Potassium ferric oxalate,* $K_3Fe\ (C_2O_4)_3$, is rapidly reduced by sunlight to the ferrous salt: —

$$2K_3Fe(C_2O_4)_3 = 2K_2Fe(C_2O_4)_2 + K_2C_2O_4 + 2CO_2$$

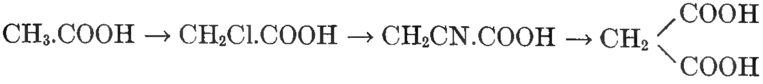
The reaction is the basis of the photographic process in which platinum prints are prepared. A sheet of paper which has been treated with a solution of potassium ferric oxalate and dried, is exposed to the sunlight under a negative. In the places where the light penetrates the negative the salt is reduced to the ferrous condition. The print is developed by placing it in a solution of platinous chloride. Platinum is precipitated from the chloride by ferrous oxalate, and is deposited on the paper wherever the ferric salt has been reduced by the sunlight.

109. Malonic Acid, $CH_2(COOH)_2$, is so-called because it was first obtained as the result of the oxidation of malic acid. The acid is of particular interest, as many important compounds can be readily prepared as the result of reactions between its esters and other substances. The so-called malonic ester synthesis will be described later (**134**). Malonic acid crystallizes from water in laminae which melt at 133°–134°, with partial decomposition. It can be prepared by a reaction which illustrates clearly the application of a general method emphasized in the case of acetic acid. The relation between acetic acid and malonic acid is shown by the formulas, —



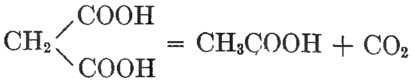
$$CH_3{-}COOH \text{ and } CH_2\begin{cases} COOH \\ COOH \end{cases}$$

The problem in the synthesis of malonic acid is to replace a hydrogen atom in acetic acid by the carboxyl group. This is accomplished in the same way as that by which methane is converted into acetic acid. One hydrogen atom is first replaced by a halogen atom, by treating acetic acid with chlorine or bromine. The substituted acid is then heated with potassium cyanide, and the cyanacetic acid so formed is hydrolyzed by boiling with a solution of an alkali. The changes are indicated by the formulas, —



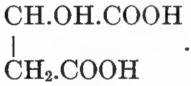
$$CH_3.COOH \rightarrow CH_2Cl.COOH \rightarrow CH_2CN.COOH \rightarrow CH_2\begin{cases} COOH \\ COOH \end{cases}$$

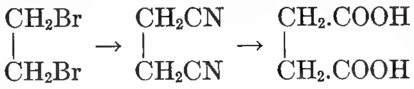
When malonic acid is heated above its melting-point (at 140°–150°) decomposition takes place quantitatively according to the equation, —



$$CH_2\begin{cases} COOH \\ COOH \end{cases} = CH_3COOH + CO_2$$

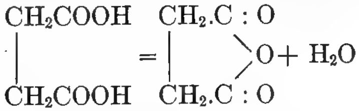
Other acids in which two carboxyl groups are joined to the same carbon atom undergo a similar decomposition. It will be recalled that most compounds which contain two hydroxyl groups linked to the same carbon atom are so unstable that they break down spontaneously with the elimination of water. Malonic acid and its derivatives are more stable than the alcohols, as heating to the melting-point is required to effect their decomposition. The decomposition is of importance as it is frequently made use of in the preparation of monobasic acids from dibasic acids of this type.

110. Succinic Acid, $(CH_2.COOH)_2$, derives its name from the fact that it occurs in amber (Latin, *succinum*). It occurs in fossilized wood, in many plants, and in the urine of horses, goats, and rabbits. Two important acids which occur in fruits are substitution-products of succinic acid. It is usually made from amber by distillation, or by the fermentation of the calcium salt of malic acid, which is a hydroxyl derivative of succinic acid,  $\begin{array}{l} CH.OH.COOH \\ | \\ CH_2.COOH \end{array}$. The acid is formed in small quantities in the alcoholic fermentation of sugar, and in the oxidation of fats by nitric acid. Succinic acid can be made by the application of the general synthetic methods of preparing acids. One method is indicated by the following formulas: —



$$\begin{array}{l} CH_2Br \\ | \\ CH_2Br \end{array} \rightarrow \begin{array}{l} CH_2CN \\ | \\ CH_2CN \end{array} \rightarrow \begin{array}{l} CH_2.COOH \\ | \\ CH_2.COOH \end{array}$$

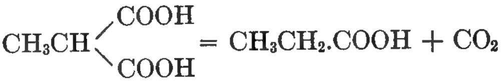
Succinic acid melts at 182°. It boils with partial decomposition at 235°; water is eliminated and an anhydride is formed: —



$$\begin{array}{l} CH_2COOH \\ | \\ CH_2COOH \end{array} = \begin{array}{l} CH_2.C:O \\ | \qquad \rangle O \\ CH_2.C:O \end{array} + H_2O$$

The same reaction is effected more completely by heating the acid with a dehydrating agent, such as phosphorus oxychloride. A small proportion of phosphorus pentachloride acts as a dehydrating agent and yields succinic anhydride. A larger proportion converts the acid into succinyl chloride.

111. Isosuccinic Acid, $CH_3CH(COOH)_2$, is isomeric with succinic acid. As it is a methyl derivative of malonic acid and contains two carboxyl groups in combination with the same carbon atom, it resembles the latter in chemical properties. For example, when heated above its melting-point it loses carbon dioxide and is converted into propionic acid: —

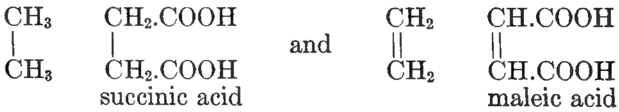


$$CH_3CH\begin{matrix}\diagup COOH\\ \diagdown COOH\end{matrix} = CH_3CH_2.COOH + CO_2$$

Dibasic acids in which the carboxyl groups are linked to different carbon atoms behave on decomposition by heat as succinic acid does, that is, they lose water and anhydrides are formed. Isosuccinic acid is prepared from α-brompropionic acid by the reactions with which the student is familiar. The acid forms crystals, which melt at 130°.

UNSATURATED DIBASIC ACIDS

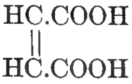
112. Fumaric and Maleic Acids, $C_2H_2(COOH)_2$. — The unsaturated dibasic acids stand in the same relation to the unsaturated hydrocarbons as do the saturated acids to the paraffins. In both cases the acids may be considered as substitution-products of the hydrocarbons in which hydrogen atoms are replaced by carboxyl groups. The relation is shown by the formulas, —



$$\begin{array}{l} CH_3 \\ | \\ CH_3 \end{array} \quad \begin{array}{l} CH_2.COOH \\ | \\ CH_2.COOH \\ \text{succinic acid} \end{array} \quad \text{and} \quad \begin{array}{l} CH_2 \\ \| \\ CH_2 \end{array} \quad \begin{array}{l} CH.COOH \\ \| \\ CH.COOH \\ \text{maleic acid} \end{array}$$

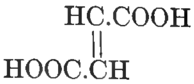
The presence of a double bond in the unsaturated acids leads to an opportunity for isomerism like that shown by crotonic and isocrotonic acids (**100**). The two forms in the case of the dicarboxyl derivatives of ethylene are represented by the formulas: —

(1)



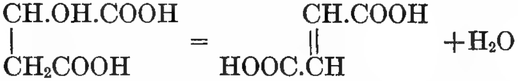
$$\begin{array}{l} HC.COOH \\ \| \\ HC.COOH \end{array}$$

and (2)



$$\begin{array}{r} HC.COOH \\ \| \quad \quad \\ HOOC.CH \quad \end{array}$$

Two acids are known to which these formulas are assigned. The *cis* form (formula 1) is given to maleic acid, and the *trans* form (formula 2) to fumaric acid. The two acids differ markedly in physical properties. Fumaric acid, which occurs somewhat widely distributed in plants, does not melt, but sublimes at about 200°. It is difficultly soluble in water. Maleic acid melts at 130°, and is readily soluble in water. Both acids can be prepared by heating malic acid, which is a hydroxyl derivative of succinic acid. If the temperature is kept at between 130° and 150° fumaric acid is obtained; when the acid is distilled, the chief product is the anhydride of maleic acid, which is readily converted into the acid by water. The reaction by which fumaric acid is obtained is represented by the equation, —



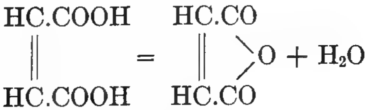
$$\begin{array}{l} CH.OH.COOH \\ | \\ CH_2COOH \end{array} = \begin{array}{r} CH.COOH \\ \| \\ HOOC.CH \end{array} + H_2O$$

This reaction is a further example of the preparation of an unsaturated compound by the removal of the elements of water from a saturated compound. While succinic acid loses water on heating and forms succinic anhydride, the decomposition of its hydroxyl derivative takes place in a manner which is analogous to that in which the hydroxyl derivatives of the monobasic acids are decomposed by heat.

The preparation of fumaric acid by treating bromsuccinic acid with potassium hydroxide is another illustration of a general method which is much used to establish a double bond in a compound: —

$$C_2H_3Br.(COOH)_2 = C_2H_2(COOH)_2 + HBr$$

Maleic acid differs from fumaric acid in that it is converted into its anyhdride when distilled: —



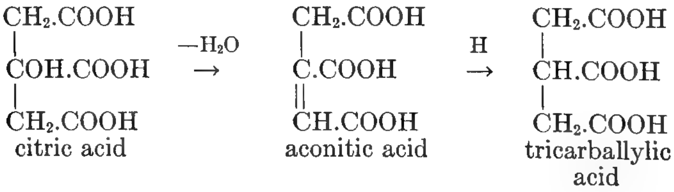
$$\begin{array}{l} HC.COOH \\ \| \\ HC.COOH \end{array} = \begin{array}{l} HC.CO \\ \| \\ HC.CO \end{array}\!\!\!\!\!\!\!\! > O + H_2O$$

It is for this reason that the *cis* formula is assigned to maleic acid. It seems probable that an anhydride could be formed more readily from a compound in which the carboxyl groups are present on the same side of the molecule, than from one in which these groups are on opposite sides. An examination of space models will make this clear. When fumaric acid is distilled, maleic anhydride is obtained. As the latter is readily converted into maleic acid by water, the reaction serves as a means of converting one isomer into the other. The conversion of maleic acid into fumaric acid may be effected by heating it for some time at a temperature slightly above its melting-point, or by bringing it into contact with the halogen hydrides at ordinary temperature.

Both maleic and fumaric acid are reduced by sodium amalgam to succinic acid — a reaction which is evidence of the correctness of the view that they are dicarboxyl derivatives of ethylene: —

$$C_2H_2(COOH)_2 + 2H = C_2H_4(COOH)_2$$

113. Aconitic Acid, $C_3H_3(COOH)_3$, is an example of an unsaturated tribasic acid. It occurs in the juice extracted from sugar-cane. It is prepared by heating citric acid at 175°. Nascent hydrogen converts the acid into tricarballylic acid. These changes are clear from the following formulas: —



$$\begin{array}{c} CH_2.COOH \\ | \\ COH.COOH \\ | \\ CH_2.COOH \\ \text{citric acid} \end{array} \xrightarrow{-H_2O} \begin{array}{c} CH_2.COOH \\ | \\ C.COOH \\ \| \\ CH.COOH \\ \text{aconitic acid} \end{array} \xrightarrow{H} \begin{array}{c} CH_2.COOH \\ | \\ CH.COOH \\ | \\ CH_2.COOH \\ \text{tricarballylic} \\ \text{acid} \end{array}$$

PROBLEMS

1. Write equations for reactions by which an acid of the structure $CH_3.CHCOOH.CH_2COOH$ may be prepared from *n*-propyl alcohol.

2. Tricarballylic acid has the composition represented by the formula $C_3H_5(COOH)_3$. Write equations for reactions by which it can be prepared from glycerol.

3. By what chemical test could you distinguish from each other (*a*) $CH_3.CH_2.CH(COOH)_2$ and $CH_3.CHCOOH.CH_2COOH$, (*b*) $CH_3.CHOH.COOH$ and $CH_3.CH_2.COOH$, (*c*) $C_2H_2(COOH)_2$ and $C_2H_4(COOH)_2$?

4. Write the graphic formulas of the compounds formed by the action of (*a*) bromine, and (*b*) hydrobromic acid on fumaric acid. Name the compounds.

5. By what reactions can (*a*) glutaric acid be converted into propane, (*b*) fumaric acid into succinic acid, (*c*) succinic acid into hydroxy-succinic acid, and (*d*) methyl alcohol into succinic acid?

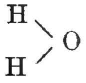
CHAPTER IX

ETHERS, ANHYDRIDES, AND ESTERS

114. In the discussion of the chemical properties of alcohols and acids, it was found convenient to consider these compounds as derived from water by the replacement of one hydrogen atom by positive (alkyl) and negative (acyl) radicals, respectively. The relation between the alcohols and inorganic bases, and between the organic and inorganic acids, is shown by the following formulas: —

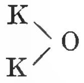
$H.OH$	$C_2H_5.OH$	$K.OH$	$CH_3CO.OH$	$NO_2.OH\ (HNO_3)$
	alcohol	base	organic acid	inorganic acid

The effect of the nature of the radical in combination with the hydroxyl group upon this group has been emphasized, and while marked similarities between the chemical behavior of alcohols and bases on one hand, and organic and inorganic acids on the other, have been noted, important differences have been pointed out. These relationships should be kept in mind in the consideration of the other substitution-products of water which will now be discussed. Three important classes of compounds are formed as the result of the replacement of both hydrogen atoms in water. In the case of inorganic compounds the substances so formed are basic oxides, acid anhydrides, and salts; for example, the formulas of three well known compounds written in this way are, —



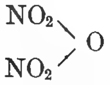
$$\left.\begin{matrix}H\\H\end{matrix}\right>O$$

water



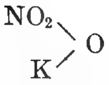
$$\left.\begin{matrix}K\\K\end{matrix}\right>O$$

potassium oxide



$$\left.\begin{matrix}NO_2\\NO_2\end{matrix}\right>O$$

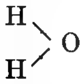
nitric anhydride



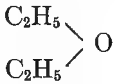
$$\left.\begin{matrix}NO_2\\K\end{matrix}\right>O$$

potassium nitrate

With the organic compounds the three possible combinations are those which contain two positive radicals, two negative radicals, and one positive and one negative radical. The three classes are known as ethers, anhydrides, and esters or ethereal salts, respectively. The following formulas are illustrative: —

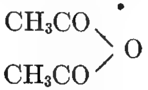


$$\left.\begin{array}{l}H\\H\end{array}\right\rangle O$$



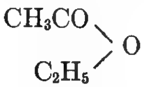
$$\left.\begin{array}{l}C_2H_5\\C_2H_5\end{array}\right\rangle O$$

ether



$$\left.\begin{array}{l}CH_3CO\\CH_3CO\end{array}\right\rangle O$$

anhydride



$$\left.\begin{array}{r}CH_3CO\\C_2H_5\end{array}\right\rangle O$$

ester

It is thus seen that the ethers resemble in composition the metallic oxides, the anhydrides the inorganic anhydrides, and the esters or ethereal salts the inorganic salts. The resemblance in composition indicated by the formulas finds expression in a similarity in chemical behavior of the analogous compounds. The differences between these organic and inorganic compounds are as marked, however, as in the case of alcohols and bases, and of organic acids and inorganic acids. The differences which are mainly of degree and not of kind are brought about as the result of the fact that the inorganic elements or groups are, in general, strongly positive or negative, whereas in the case of the organic compounds the positive or negative nature of the radicals are not so highly developed. The ethers are thus only weakly basic, and the esters resemble inorganic salts which are the product of the interaction of a weak acid and a weak base.

115. Ethyl Ether, $(C_2H_5)_2O$, is the most important member of the class of compounds known as ethers. It is usually called ether (without the prefix ethyl). It is a very mobile, colorless liquid, which boils at 34.6° and solidifies at — 117.6°. On account of its low boiling-point it is very volatile, and, as its vapor forms an explosive mixture with air, great care must be exercised in its use. Ether is an excellent solvent for many organic substances, and is much used in the laboratory for crystallization and for extraction of substances from aqueous solutions. One volume of ether dissolves in about 11 volumes of water at 25°. As it is less soluble in water which is saturated with sodium chloride, the latter is frequently added to aqueous solutions which are to be extracted. Ether dissolves about two per cent of its volume of water. It has the specific gravity 0.718 at 15.6°. Continued inhalation of the vapor of ether causes unconsciousness. As its physiological effects can be more readily controlled than those of chloroform, it is widely used in surgery as an anæsthetic.

Ether is usually prepared by the action of concentrated sulphuric acid on alcohol. For this reason it is sometimes called "sulphuric ether." Alcohol reacts with sulphuric acid when heated to 130°–140° to form ethyl sulphuric acid, which is the acid ethyl ester of sulphuric acid: —

$$C_2H_5OH + H_2SO_4 = C_2H_5.H.SO_4 + H_2O$$

It will be recalled that the same reaction takes place in the preparation of ethylene (**29**), which is formed when the ester is heated to about 170°. If the temperature is maintained at 130°–140° and alcohol is allowed to flow through the heated compound, a further reaction takes place according to the equation, —

$$C_2H_5.H.SO_4 + C_2H_5OH = (C_2H_5)_2O + H_2SO_4$$

The sulphuric acid regenerated serves to convert more alcohol into ether. The process is thus a so-called continuous one. As only a part of the water formed distills over with the ether, the acid, which becomes more and more diluted as the reaction proceeds, finally ceases to react with the alcohol and the production of ether stops. Other reactions take place which tend to interfere with the process; at the temperature used a part of the alcohol is oxidized and the sulphuric acid is reduced to sulphur dioxide. Notwithstanding these facts, sulphuric acid will convert about three times its weight of alcohol into ether before the process becomes inefficient.

Ether prepared by this process contains water, acid, and alcohol. It is purified by shaking it a number of times with small quantities of water, which free it from most of the alcohol. Acid is removed by shaking with a solution of sodium hydroxide. The ether is allowed to stand some hours in contact with anhydrous calcium chloride, from which it is distilled. This treatment removes most of the alcohol and water. Final purification is effected by adding metallic sodium in the form of a fine wire, or thin shavings, and distilling when the evolution of hydrogen ceases and a fresh portion of sodium is without action. Ether should not be heated over a free flame, as its vapor is heavy and is apt to fall on the flame and ignite. It should be distilled from a bath which contains warm water.

116. Ether can be prepared from alcohol by a method which has great historical interest, as it was through the discovery of this method that the structure of ethers and their relation to the alcohols were first made clear. When ethyl iodide is heated with sodium ethylate ether is formed: —

$$C_2H_5ONa + C_2H_5I = C_2H_5OC_2H_5 + NaI$$

It has already been shown that in sodium ethylate sodium is joined to oxygen. The simplest interpretation of the reaction just given — and the one which has proved correct — is that the ethyl group in the iodide takes the place of the sodium atom in the ethylate; sodium iodide and ether are formed. The formation of the so-called mixed ethers — compounds which contain two different alkyl groups linked to oxygen — is further evidence of the correctness of this interpretation of the reaction. When sodium methylate is heated with ethyl iodide, methyl-ethyl ether is formed: —

$$CH_3ONa + C_2H_5I = CH_3OC_2H_5 + NaI$$

If the view of the structure of ethers put forward is correct, we should expect to be able to prepare methyl-ethyl ether as the result of the interaction of sodium ethylate and methyl iodide, thus, —

$$C_2H_5ONa + CH_3I = C_2H_5OCH_3 + NaI$$

As methyl-ethyl ether can be prepared in both these ways the view that it and other ethers are oxides of radicals in which the two alkyl groups are joined directly to oxygen, appears to have a satisfactory experimental basis.

117. The synthesis of ether indicates that it is an oxide. It does not, however, react readily with acids, nor does its aqueous solution affect indicators. In these respects it resembles the alcohols in which the properties of a base are but slightly developed. When ether is warmed with concentrated hydriodic acid, a reaction takes place which is analogous to that between a metallic oxide and an acid. Ethyl iodide is formed according to the equation, —

$$(C_2H_5)_2O + 2HI = 2C_2H_5I + H_2O$$

The reaction takes place quantitatively only in the presence of a large excess of the acid. With hydrochloric acid and hydrobromic acid analogous reactions do not take place so readily. The difference in chemical activity of the halogen acids, which has already been mentioned, is further emphasized by this case.

Ether dissolves in cold concentrated sulphuric acid. Addition of water to the mixture causes the precipitation of the ether unchanged. When gently heated with the acid, however, a reaction takes place in which the ether acts as an oxide, and a salt is formed: —

$$(C_2H_5)_2O + H_2SO_4 = 2C_2H_5.H.SO_4$$

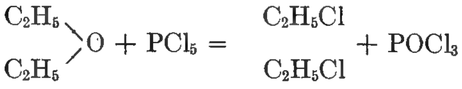
When heated with water in the presence of a small amount of acid, ether is converted into alcohol: —

$$(C_2H_5)_2O + H_2O = 2C_2H_5OH$$

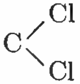
This reaction indicates that ether may be considered as the anhydride of alcohol.

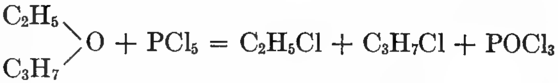
Toward many of the common reagents ether is inert. It is unaffected by alkalies and metallic sodium, and dissolves in the cold the halides of phosphorus without undergoing change. By evaporation of the solution of phosphorus pentachloride in ether a crystalline compound of the composition $(PCl_5)_3.[(C_2H_5)_2O]_2$ may be obtained. Ether forms similar so-called molecular compounds with a number of substances. Examples of these are substances to which have been assigned the formulas $(C_2H_5)_2O.Br_2$, $(C_2H_5)_2O.AlBr_3$ and $(C_2H_5)_2O.SnCl_4$. The structure of these compounds has not been definitely established. It is probable that in them the oxygen atom exhibits a valence of four and serves as a means of linking the molecules together. When ether dissolves in concentrated sulphuric acid a molecular compound is probably formed.

118. When ether is heated with phosphorus pentachloride, the oxygen is replaced by its equivalent — two atoms — of chlorine: —



$$\begin{matrix} C_2H_5 \\ C_2H_5 \end{matrix}\!\!>\!O + PCl_5 = \begin{matrix} C_2H_5Cl \\ C_2H_5Cl \end{matrix} + POCl_3$$

As chlorine is univalent two molecules of ethyl chloride are formed from one molecule of ether. It will be remembered that phosphorus pentachloride reacts in general with organic compounds which contain oxygen, and that in the reaction the oxygen enters into combination with phosphorus. The composition of the organic compound obtained gives valuable information as to the structure of the original substance. It will be recalled that, if as the result of the reaction one hydrogen and one oxygen atom are replaced by one chlorine atom, the substance under investigation is a hydroxyl derivative. If, on the other hand, one oxygen is replaced by two chlorine atoms, and the molecule does not undergo other decomposition, the original compound contains the carbonyl group, $C=O$, which is converted by the reaction into the group  $\mathrm{C}\genfrac{}{}{0pt}{}{\diagup \mathrm{Cl}}{\diagdown \mathrm{Cl}}$. In the case of ethers it is now seen that one oxygen atom is replaced by two chlorine atoms and two molecules are obtained from one of the ether. With mixed ethers two halides are obtained, for example, —



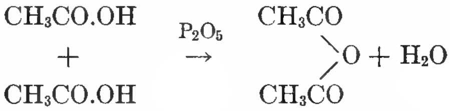
$$\genfrac{}{}{0pt}{}{C_2H_5\diagdown}{C_3H_7\diagup}O + PCl_5 = C_2H_5Cl + C_3H_7Cl + POCl_3$$

Chlorine and bromine react with ether and replace the hydrogen atoms by halogen. The reaction is analogous to that of these halogens on the hydrocarbons, acids, and other organic compounds. The extent of the substitution is affected by the temperature and the presence or absence of a catalytic agent and sunlight — conditions, it will be recalled, which are of the first importance in the replacement by halogen of hydrogen joined to carbon. The first product of the action of chlorine in the dark has the structure $CH_3CH_2Cl.O.C_2H_5$. Substitution-products are known up to the so-called perchlorether $(C_2Cl_5)_2O$.

119. Properties of the Ethers of Analytical Significance. — Many homologues of ether are known. With the exception of those of very high molecular weight they are liquids, which have a specific gravity less than one, and are almost insoluble in water. Many ethers are decomposed when boiled with concentrated hydriodic acid, and alkyl halides are obtained. The inertness of ethers towards the reagents which are used to test for the presence of the characteristic groups in other compounds, serves as a guide in the determination of an unknown substance as an ether. Metallic sodium, which reacts with many organic compounds, does not affect ethers. Most of the ethers, like many other compounds which contain oxygen, are soluble without decomposition in cold concentrated sulphuric acid, from which they are precipitated unchanged on dilution with water. This behavior often serves to distinguish and separate ethers from other more or less inert substances, such as the hydrocarbons, alkyl halides, etc.

Acid Anhydrides

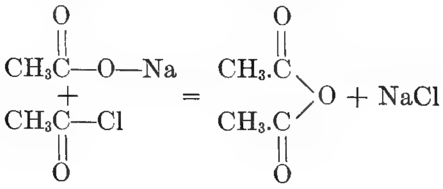
120. Acetic Anhydride, $(CH_3CO)_2O$, is the most important member of this class. It is a liquid which has an unpleasant, sharp odor, and boils at 136°. Its specific gravity is 1.080 at 15°. Acetic anhydride is formed when acetic acid is heated with phosphorus pentoxide: —



$$\begin{array}{c} CH_3CO.OH \\ + \\ CH_3CO.OH \end{array} \xrightarrow{P_2O_5} \left.\begin{array}{l} CH_3CO \\ \\ CH_3CO \end{array}\right\rangle O + H_2O$$

As the yield is poor the reaction is not used as a method of preparing the compound. It is of interest, however, in showing the relation between acetic acid and its anhydride — a relation analogous to that between sulphuric acid and sulphuric anhydride, which may be obtained by the action of phosphorus pentoxide on sulphuric acid.

According to the view of the structure of acetic anhydride which has been given, the compounds consist of two acetyl (CH_3CO) groups in combination with oxygen. Evidence of the correctness of this conception is furnished by the reaction by which the anhydride is readily prepared. The method consists in heating a mixture of sodium acetate and acetyl chloride:



$$\begin{array}{l} CH_3\overset{\overset{O}{\|}}{C}—O—Na \\ \quad + \\ CH_3\underset{\underset{O}{\|}}{C}—Cl \end{array} = \left.\begin{array}{l} CH_3.\overset{\overset{O}{\|}}{C} \\ CH_3.\underset{\underset{O}{\|}}{C} \end{array}\right\rangle O + NaCl$$

The reaction is analogous to that by which ether is prepared from sodium ethylate and ethyl iodide. It is an example of a general reaction which may be written, —

$$R{-}O{-}Na + RCl = R{-}O{-}R + NaCl$$

where R represents an alkyl or acyl radical. In the case of acetic anhydride the radicals are both acetyl groups.

The chemical behavior of acetic anhydride is in accord with the view of its structure which has been given. Like the anhydrides of inorganic acids it is converted by water into an acid: —

$$(CH_3CO)_2O + H_2O = 2CH_3COOH$$

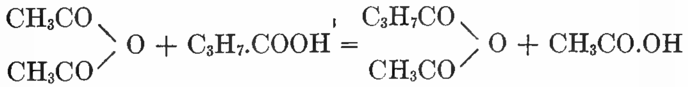
The reaction takes place rapidly in warm water.

Acetic anhydride reacts with compounds which contain the hydroxyl group. If this group is in combination with a positive radical the reaction takes place readily. For example, with alcohol, ethyl acetate is formed according to the equation, —

$$C_2H_5OH + (CH_3CO)_2O = CH_3CO.OC_2H_5 + CH_3COOH$$

As a result of the reaction the hydrogen in the hydroxyl group in alcohol is replaced by the acetyl group. If a diatomic alcohol is used two acetyl groups are introduced. The reaction is of great analytical value as by means of its use the number of hydroxyl groups present in a substance of unknown structure can be determined.

121. Acetic anhydride reacts slowly and only at somewhat elevated temperatures with compounds which contain the hydroxyl group in combination with a negative or acid radical. Thus, when it is heated with butyric acid the hydrogen in the hydroxyl group is replaced by acetyl as in the case of alcohols: —



$$\left.\begin{array}{l}CH_3CO\\CH_3CO\end{array}\right\rangle O + C_3H_7.COOH = \left.\begin{array}{l}C_3H_7CO\\CH_3CO\end{array}\right\rangle O + CH_3CO.OH$$

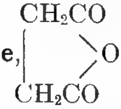
The method serves, therefore, as a means of preparing mixed anhydrides.

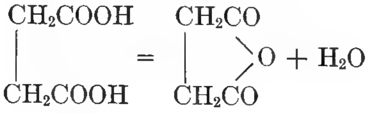
Acetic anhydride reacts with ammonia and forms a compound, called acetamide, in which one hydrogen atom of the ammonia is replaced by the acetyl group:—

$$(CH_3CO)_2O + 2NH_3 = CH_3CO.NH_2 + CH_3COONH_4$$

Compounds like acetamide, which are derivatives of acids in which the hydroxyl group is replaced by the NH_2 group, are of great importance, as they occur widely distributed in nature. They will be discussed in detail later. With chlorine and bromine acetic anhydride forms substitution-products.

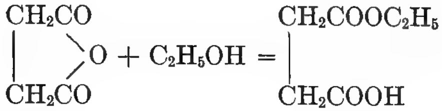
A number of *homologues of acetic anhydride* are known. Those of high molecular weight are solids and have a specific gravity slightly less than one. The anhydrides are insoluble in water, but dissolve in ether. Their boiling-points are higher than those of the corresponding acids; thus acetic acid boils at 119° and its anhydride at 136°. They are all converted by water into acids, the reaction taking place more and more slowly with increasing molecular weight. The higher anhydrides can be treated with boiling water for some time with only partial conversion into the acid. Aqueous solutions of the alkalies, however, bring about the change rapidly.

122. Succinic anhydride,  $\begin{array}{l} CH_2CO \\ \vert \qquad \rangle O \\ CH_2CO \end{array}$, is an example of an anhydride of a dibasic acid. Like the anhydrides of other dibasic acids in which the carboxyl groups are separated by *two* or *three* carbon atoms, it can be prepared by distilling the acid alone, or with better yield in the presence of a dehydrating agent. Acetic anhydride, acetyl chloride, or phosphorus oxychloride readily brings about the elimination of water:—



$$\begin{array}{l} CH_2COOH \\ \vert \\ CH_2COOH \end{array} = \begin{array}{l} CH_2CO \\ \vert \qquad \rangle O \\ CH_2CO \end{array} + H_2O$$

Succinic anhydride is a colorless, crystalline substance, which melts at 120° and boils at 261°. It resembles the anhydrides of the fatty acids, being converted into the acid when boiled with water and into the acid ethyl ester when warmed with alcohol: —



$$\begin{matrix} CH_2CO \\ | \quad\quad \\ CH_2CO \end{matrix} \!\!>\! O + C_2H_5OH = \begin{matrix} CH_2COOC_2H_5 \\ | \\ CH_2COOH \end{matrix}$$

123. Properties of Acid Anhydrides of Analytical Significance. — In the identification of a substance as an acid anhydride, the conclusion is reached as the result of evidence that the compound contains only carbon, hydrogen, and oxygen, is neutral, is converted into an acid by water, and into an ester when treated with alcohol. As the chlorides, bromides, and iodides of the acids undergo similar changes the absence of halogen in the original compound must be proved. It has been pointed out that some anhydrides react slowly with water; in fact, some can be crystallized from this solvent unchanged. The apparent stability of a compound with water should not, therefore, lead to the definite conclusion that it is not an acid anhydride. Such anhydrides are readily converted into the sodium salts of the corresponding acid when warmed with a solution of sodium hydroxide. As esters yield sodium salts and alcohols when treated in this way, care should be taken to determine whether an alcohol is formed when the substance under study is decomposed by a solution of the base. The anhydride should be converted into an amide by treatment with ammonia in order to confirm the conclusions reached as the result of the application of the test just given. The determination of the melting-points or boiling-points of the original substance and of the acid, ester, or amide prepared from it, serves to complete the identification of a substance the properties of which have already been described.

ESTERS

124. The esters are organic derivatives of acids in which the hydrogen atom of the acidic hydroxyl group is replaced by an alkyl radical. As many esters are volatile liquids they are sometimes called ethereal salts. While, as will be shown later, the esters take part in certain reactions analogous to those characteristic of salts, they differ markedly from the latter in certain important respects. For example, while salts are highly ionized and enter instantaneously into reactions of double decomposition, the esters are not appreciably ionized, and the reactions in which they take part are often of a different character from those of salts. These differences are, no doubt, due to the fact that the alkyl radicals are only very weakly basic as compared with metals. The esters bear a striking resemblance to inorganic salts which are formed as the result of the interaction of a weak acid and a weak base. Like such salts they are hydrolyzed by water, but even in this case there is a difference, as the hydrolysis of salts takes place rapidly, whereas with esters reaction proceeds so slowly that its rate can be accurately measured. The reactions in the two cases are illustrated by the two equations, —

$$KCN + H_2O = KOH + HCN$$
$$CH_3COO.C_2H_5 + H_2O = C_2H_5OH + CH_3COOH$$

Esters were formerly called compound ethers, and are sometimes named as such; thus acetic ether is a name given to the ethyl ester of acetic acid.

Esters occur widely distributed in nature and give the characteristic odor to many flowers and fruits. They are manufactured in large quantities, and are used in perfumery and flavoring extracts.

ESTERS OF INORGANIC ACIDS

125. The esters of a number of inorganic acids are known. Those derived from the strong acids may be prepared directly from the acid and alcohol. In the case of the weak acids the esters can be prepared as the result of the interaction of the silver salt of the acid with an alkyl halide; for example, ethyl sulphite may be made by the reaction expressed by the equation,

$$2C_2H_5I + Ag_2SO_3 = (C_2H_5)_2SO_3 + 2AgI$$

Only a few esters of inorganic acids will be described here. The esters of the halogen acid, which have been frequently mentioned, are discussed at length in section **204**.

Ethyl Nitrate, $C_2H_5NO_3$, is a liquid, heavier than water, which possesses a pleasant fruity odor, and boils at 87°. It is prepared by the action of nitric acid on alcohol: —

$$C_2H_5OH + HNO_3 = C_2H_5NO_3 + H_2O$$

Heat is developed by the reaction, a part of the alcohol is oxidized, and a part of the acid reduced to nitrous acid, which forms ethyl nitrite with the alcohol present. The nitrate obtained in this way is, therefore, impure. In order to prevent the formation of ethyl nitrite, urea (**180**) is added to the mixture to interact with the nitrous acid formed: —

$$CO(NH_2)_2 + 2HNO_2 = CO_2 + 2N_2 + 3H_2O$$

Unless carefully controlled the reaction between alcohol and concentrated nitric acid is apt to take place with explosive violence.

Ethyl nitrate is hydrolyzed by boiling water: —

$$C_2H_5NO_3 + H_2O = C_2H_5OH + HNO_3$$

When reduced by the hydrogen generated by the action of tin on hydrochloric acid it is converted into alcohol and hydroxylamine: —

$$C_2H_5O.N:O_2 + 6H = C_2H_5OH + NH_2OH + H_2O$$

126. Ethyl Nitrite, $C_2H_5NO_2$, is a liquid which boils at 17° and is soluble in water. It is prepared by passing into alcohol the oxides of nitrogen formed by the action of concentrated nitric acid on arsenous oxide. The equations which express the reactions may be written, —

$$As_2O_3 + 2HNO_3 = 2H_3AsO_4 + N_2O_3,$$
$$2C_2H_5OH + N_2O_3 = 2C_2H_5NO_2 + H_2O$$

Another convenient method of preparing ethyl nitrite is to distill a mixture of alcohol, sodium nitrite, and concentrated sulphuric acid.

Ethyl nitrite shows the reactions characteristic of an ethereal salt. It is readily hydrolyzed by water. This action and the fact that on reduction it yields alcohol and hydroxylamine are evidence that its structure should be represented by the formula $C_2H_5—O—N=O$.

An alcoholic solution of ethyl nitrite is a pharmaceutical preparation sold under the name of "sweet spirit of nitre."

Isoamyl Nitrite, $C_5H_{11}NO_2$, which is used in the preparation of certain substances known as diazo compounds, is prepared from isoamyl alcohol by a method which is analogous to that used in the preparation of ethyl nitrite. It is a liquid of penetrating odor, which causes flushing of the face and vascular throbbing. Amyl nitrite is a valuable remedy used in medicine. Its physiological action is similar to that of glyceryl nitrate. It boils at 99°.

Methyl Sulphate, $(CH_3)_2SO_4$, is an oily liquid which boils at 188°. On account of its low cost it is frequently used instead of methyl iodide to introduce the methyl group into organic compounds. It is prepared by distilling under diminished pressure methyl hydrogen sulphate, which is formed by gently heating a mixture of methyl alcohol and sulphuric acid: —

$$CH_3OH + H_2SO_4 = CH_3.H.SO_4 + H_2O$$
$$2CH_3.H.SO_4 = (CH_3)_2.SO_4 + H_2SO_4$$

127. Ethyl Hydrogen Sulphate, $C_2H_5.H.SO_4$, is an oily liquid, resembling sulphuric acid, which can not be distilled without decomposition. It is usually called ethyl sulphuric acid as it contains a hydrogen atom replaceable by metals. The acid is formed by heating at about 100° a mixture of alcohol with an excess of concentrated sulphuric acid over that required by the equation, —

$$C_2H_5OH + H_2SO_4 = C_2H_5.H.SO_4 + H_2O$$

The acid may be separated from the excess of sulphuric acid by taking advantage of the fact that its barium salt is soluble in water, while barium sulphate is insoluble.

Ethyl sulphuric acid is both an acid and an ester. When heated with water it is hydrolyzed: —

$$C_2H_5.H.SO_4 + H_2O = C_2H_5OH + H_2SO_4$$

The salts of ethyl sulphuric acid and similar compounds are frequently used in the preparation of other substances. For example, ethyl bromide and ethyl cyanide may be prepared by reactions which take place according to the following equations:

$$C_2H_5.H.SO_4 + KBr = C_2H_5Br + KHSO_4$$
$$C_2H_5.H.SO_4 + KCN = C_2H_5CN + KHSO_4$$

ESTERS OF ORGANIC ACIDS

The general methods of preparation and the properties of the members of this class of compounds, of which many are known, can best be made clear by a detailed consideration of a typical member of the group.

128. Ethyl Acetate, $CH_3.COOC_2H_5$, the ethyl ester of acetic acid, is a colorless liquid of pleasant odor, which boils at 77° and has the specific gravity 0.9028 at $\frac{18°}{4°}$. It is soluble in 17 parts of water at 17.5°. It is formed as the result of the interaction of alcohol and acetic acid: —

$$CH_3.COOH + C_2H_5OH = CH_3.COOC_2H_5 + H_2O$$

The reaction takes place very slowly at room-temperature, and even when the mixture is heated many hours, complete reaction according to the equation does not take place. This is due to the slow rate of the reaction and to the fact that it is a reversible one. Reactions can take place according to the above equation when read either from left to right or from right to left. As the transformation of the acid into ester proceeds, a point is reached at which the ester formed from alcohol and acid is equal in amount to that hydrolyzed by the water which is formed in the reaction. When the so-called equilibrium is reached, further heating does not affect the course of the reaction. When equal molecular quantities of alcohol and acetic acid are heated, equilibrium is arrived at when about two-thirds of the acid has been converted into ester. The temperature at which the reaction is carried out has little effect on the equilibrium. Thus at 10° the limit of esterification is 65.2 per cent, while at 220° it is but 66.5 per cent. The rate at which equilibrium is reached, however, is markedly affected by temperature. In general, the rate of a reaction which is dependent upon temperature is doubled for each increase of ten degrees. It is clear from this why reacting substances are so frequently heated in the preparation of organic compounds.

In order to increase the yield of ethyl acetate or other esters, when prepared from an alcohol and an acid, a dehydrating agent is added to the reacting mixture. This serves to remove the water formed in the reaction and thus prevent the hydrolysis of the ester sought. Sulphuric acid or hydrogen chloride are frequently used for this purpose. The former is usually used in the preparation of ethyl acetate. It not only acts as a dehydrating agent, but facilitates the formation of the ester by converting the alcohol into ethyl sulphuric acid, which reacts with acetic acid according to the equation, —

$$C_2H_5.H.SO_4 + CH_3.COOH = CH_3.COOC_2H_5 + H_2SO_4$$

Ethyl acetate is readily prepared by allowing a mixture of alcohol and acetic acid, in equivalent quantities, to flow into a mixture of alcohol and sulphuric acid heated to 140°. The sulphuric acid that takes part in the reaction is regenerated and the process is, accordingly, a continuous one, which, however, is subject to the limitations mentioned in the case of the similar process employed in the preparation of ether.

Ethyl acetate prepared in this way may contain as impurities alcohol, acetic acid, water, and ether. Alcohol is removed by shaking the ester with a saturated aqueous solution of calcium chloride, acetic acid by treatment with a solution of sodium carbonate, and water by distillation after allowing the ester to stand some hours in contact with anhydrous calcium chloride. If ether is present it must be removed by fractional distillation.

129. Ethyl acetate may be formed by synthetical methods which are frequently used in the preparation of other members of this class. It is formed when alcohol is treated with acetic anhydride or acetyl chloride. The reactions which take place have already been mentioned. They are expressed by the equations, —

$$C_2H_5OH + (CH_3CO)_2O = CH_3COOC_2H_5 + CH_3COOH$$
$$C_2H_5OH + CH_3COCl = CH_3COOC_2H_5 + HCl$$

These reactions are of importance as they are examples of general reactions by which esters are formed as the result of the interactions of alcohols and anhydrides or acid chlorides.

A third method by which ethyl acetate may be formed is analogous to one of the methods used in the preparation of ethers and anhydrides. It consists in heating a salt of acetic acid with an ethyl halide: —

$$CH_3COOK + C_2H_5I = CH_3COOC_2H_5 + KI$$

As in the two cases mentioned, the substance sought is formed as the result of the treatment of a compound containing a metal with a halogen derivative. The three cases differ only in the nature of the organic radicals in the compounds used. In the case of ethers both radicals are alkyl groups, while with esters one is an alkyl and the other an acyl group. The syntheses of these three classes of compounds bring out very clearly the relationship between them. The equations for the reactions are repeated here in order to emphasize this relationship: —

$$C_2H_5.ONa + C_2H_5.Br = C_2H_5.O.C_2H_5 + NaBr$$
$$CH_3CO.ONa + CH_3CO.Cl = CH_3CO.O.CH_3CO + NaCl$$
$$CH_3CO.ONa + C_2H_5.Br = CH_3CO.O.C_2H_5 + NaBr$$

130. In chemical properties the esters resemble in some respects the ethers on one hand, and the anhydrides on the other. It will be recalled, for example, that ethers are hydrolyzed by water only slowly even at high temperatures, while many anhydrides undergo hydrolysis with cold water. The positive radicals in ethers and the negative radicals in anhydrides are the cause of this difference. Esters, which contain one of each kind of radical in combination with oxygen, stand between these two classes in their behavior with water. Most esters undergo hydrolysis slowly with boiling water. Addition of an alkali markedly increases the rate of the reaction. In the case of ethyl acetate decomposition according to the following equation takes place rapidly when the ester is heated with an aqueous solution of sodium hydroxide: —

$$CH_3COOC_2H_5 + NaOH = CH_3COONa + C_2H_5OH$$

Esters like ethers react with hydriodic acid when heated with a concentrated aqueous solution of the acid: —

$$CH_3COOC_2H_5 + HI = CH_3COOH + C_2H_5I$$

Like ethers, also, they are soluble in cold concentrated sulphuric acid without decomposition, and are decomposed by the hot acid: —

$$CH_3COOC_2H_5 + H_2SO_4 = CH_3COOH + C_2H_5.H.SO_4$$

On the other hand, they resemble anhydrides in their behavior with ammonia. A convenient way of preparing the substances known as amides is to treat esters with ammonia. When ethyl acetate is allowed to stand in contact with a saturated aqueous solution of ammonia, a good yield of acetamide is obtained. The equations for the reactions in the case of ethyl acetate and acetic anhydride are, —

$$CH_3CO.OC_2H_5 + NH_3 = CH_3CO.NH_2 + C_2H_5OH$$
$$(CH_3CO)_2O + 2NH_3 = CH_3CO.NH_2 + CH_3COONH_4$$

Ethers do not undergo a similar change.

HOMOLOGUES OF ETHYL ACETATE

131. The esters of the fatty acids resemble ethyl acetate in physical properties and in their behavior with other substances. It has been stated that they possess characteristic odors, and that some are manufactured and used in artificial flavoring extracts. As examples may be given *iso-amyl acetate*, $CH_3COOC_5H_{11}$, which on account of its odor is sometimes called pear oil, *methyl butyrate*, $C_3H_7COOCH_3$, which has the odor of pineapples, *iso-amyl isovalerate*, $C_4H_9COOC_5H_{11}$, which has that of apples, and octyl acetate, $CH_3COOC_8H_{17}$, the odor of which resembles that of oranges.

Most of the esters of the monobasic acids are liquids which have specific gravities less than one, and are insoluble in water. Some of high molecular weight are solids; for example, *cetyl palmitate*, $C_{15}H_{31}COOC_{16}H_{33}$, forms crystals which melt at 49°.

Esters can be prepared in many cases by the action of alcohols on acids in the presence of sulphuric acid. Certain alcohols are very readily converted into unsaturated hydrocarbons by concentrated sulphuric acid. For this and other reasons hydrogen chloride is frequently used instead of sulphuric acid. The part played by the halogen acid in effecting the elimination of water is not definitely understood. One explanation offered is that a small quantity of acid chloride is formed which then reacts with the alcohol present to form the ester. In the case of the formation of ethyl acetate the reactions according to this hypothesis are, —

$$CH_3COOH + HCl = CH_3COCl + H_2O$$
$$CH_3COCl + C_2H_5OH = CH_3COOC_2H_5 + HCl$$

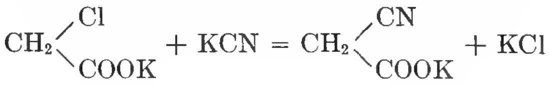
The hydrochloric acid regenerated by the second reaction serves to convert more acid into chloride and the process is, therefore, continuous. Ethyl esters are prepared by this method by saturating an alcoholic solution of the acid with dry hydrogen chloride, and by pouring the mixture into water after standing sometime, when the ester is precipitated. It is often more convenient to saturate with hydrogen chloride only about four to five per cent of the alcohol to be used, and to boil a mixture of the solution so prepared with the rest of the alcohol and organic acid for two or three hours. The ester is obtained, as before, by precipitation with water.

132. The extent to which a reaction takes place between an alcohol and an acid is markedly affected by the nature of the radicals present in each. A quantitative study of the rate of the reaction and the equilibria reached when alcohols and acids of different structures are heated together, has brought out some interesting facts in regard to the effect of structure on chemical activity. When primary alcohols are heated in sealed tubes for an hour at 154° with an equivalent quantity of acetic acid, about 47 per cent of the alcohol is converted into ester. Secondary alcohols under the same conditions yield about 22 per cent of ester, and tertiary alcohols only about 1.5 per cent. These results illustrate clearly the great effect on the reactivity of a compound of the nature of the radical which it contains. They also serve to emphasize the difference between primary, secondary, and tertiary alcohols, which has already been discussed. It will be remembered that the general formulas of these three classes of alcohols are $RCH_2.OH$, $RR'CH.OH$, and $RR'R''C.OH$, respectively. Experiments in which the rate of esterification of one alcohol with acids of varying structures brought out similar results in regard to the effect of the nature of the radicals on the activity of acids. Acids which contained a primary radical, $RCH_2.COOH$, were converted into esters the most rapidly, and those containing secondary alkyl, $RR'CH.COOH$, less rapidly. Esters were formed very slowly from acids which contained a tertiary group, $RR'R''C.COOH$. The exact significance of these and other results of a similar nature has not as yet been made clear. It is probable that a quantitative study of the effect of structure on chemical activity will eventually throw much light on the nature of molecules and on the manner in which they react with one another.

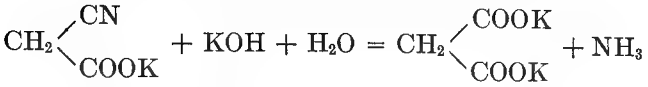
The quantitative study of the rate of hydrolysis of esters has led to results of the greatest value to the science of chemistry in general. The fact has been mentioned that the rate of hydrolysis is markedly affected by the presence of acids or bases, which are said to act as catalytic agents. The experimental results obtained show that the rate is determined by the concentration of the hydrogen or hydroxyl ions, and is independent of the acid used. After the rate of hydrolysis of an ester with an acid of known ionization has been determined, a study of the rate of hydrolysis of the same ester with other substances which produce hydrogen ions, serves to determine the extent of ionization of these substances. The nature of catalytic action has become more thoroughly understood as the result of the quantitative study of reactions of hydrolysis.

ESTERS OF DIBASIC ACIDS

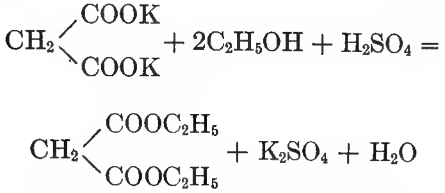
133. Ethyl Malonate, $CH_2(COOC_2H_5)_2$, which is often called malonic ester, is the most important member of this class on account of its frequent use in syntheses. It can be prepared from alcohol and malonic acid but is usually made from chloracetic acid by the reactions indicated by the following equations: —



$$\mathrm{CH_2}\begin{matrix}\diagup\mathrm{Cl}\\ \diagdown\mathrm{COOK}\end{matrix} + \mathrm{KCN} = \mathrm{CH_2}\begin{matrix}\diagup\mathrm{CN}\\ \diagdown\mathrm{COOK}\end{matrix} + \mathrm{KCl}$$



$$CH_2\Big\langle\begin{matrix}CN\\COOK\end{matrix} + KOH + H_2O = CH_2\Big\langle\begin{matrix}COOK\\COOK\end{matrix} + NH_3$$



$$CH_2\Big\langle\begin{matrix}COOK\\COOK\end{matrix} + 2C_2H_5OH + H_2SO_4 =$$

$$CH_2\Big\langle\begin{matrix}COOC_2H_5\\COOC_2H_5\end{matrix} + K_2SO_4 + H_2O$$

Ethyl malonate is a liquid of faint odor, which boils at 198° and has a specific gravity of 1.061 at 15°.

When a mixture of ethyl malonate and phosphorus pentoxide is slowly heated at 300°, decomposition takes place and an oxide of carbon having the composition C_3O_2 is formed: —

$$CH_2(COOC_2H_5)_2 = C_3O_2 + 2C_2H_4 + 2H_2O$$

As the compound contains a smaller percentage of oxygen than the other oxides of carbon, it is called *carbon suboxide.* It is a pungent gas which can be condensed to a liquid that boils at 7°. It reacts quickly with water to form malonic acid. The structure of carbon suboxide has not been definitely established.

134. Malonic Ester Synthesis. — When ethyl malonate is treated with sodium, hydrogen is evolved and a compound is formed from the ester as the result of the replacement of hydrogen by the metal. If the weights of the substances taken are in the relation of one molecular weight of the ester to one atomic weight of sodium, the resulting compound has the composition represented by the formula $CHNa(COOC_2H_5)_2$. If twice as much sodium is used, two atoms of the metal are introduced and the formula of the sodium derivative is $CNa_2(COOC_2H_5)_2$. The structure of these sodium derivatives has not been definitely established, but many of their reactions can be interpreted most readily with the aid of the formulas given, and, accordingly, they will be used in the considerations which follow. Monosodium and disodium malonic ester, like other organic compounds which contain metals, react with many organic substances which contain halogen atoms. Two typical reactions are represented by the equations, —

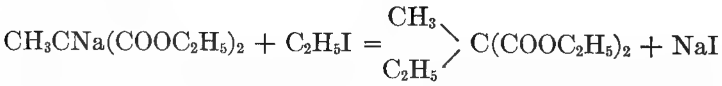
$$NaCH(COOC_2H_5)_2 + C_2H_5I = C_2H_5CH(COOC_2H_5)_2 + NaI$$
$$Na_2C(COOC_2H_5)_2 + 2C_2H_5I = (C_2H_5)_2C(COOC_2H_5)_2 + NaI$$

By saponification of the products of the reaction, dibasic acids are obtained. As the ethyl iodide given in the reactions above can be replaced by many other halogen compounds, it is evident that this synthetic method can be used in the preparation of a large number of compounds of this type.

It will be recalled that dibasic acids which contain two carboxyl groups in combination with the same carbon atom, readily pass into monobasic acids, with loss of carbon dioxide, when heated. This fact renders the malonic ester synthesis of great value in the preparation of monobasic acids. When the acids which have been just used as illustrations are heated, they decompose according to the equations, —

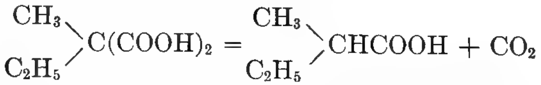
$$C_2H_5.CH(COOH)_2 = C_2H_5CH_2.COOH + CO_2$$
$$(C_2H_5)_2C.(COOH)_2 = (C_2H_5)_2CH.COOH + CO_2$$

If it is desired to introduce two different radicals the synthesis is carried out in steps: From ethyl malonate can be obtained the ester formed by the replacement of one hydrogen by an alkyl group, for example, $CH_3CH(COOC_2H_5)_2$. This, like the ester of malonic acid, reacts with sodium and forms a derivative which may be condensed with a molecule of another alkyl halide, thus, —



$$CH_3CNa(COOC_2H_5)_2 + C_2H_5I = \begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>C(COOC_2H_5)_2 + NaI$$

A monobasic acid is formed, as before, by heating the acid obtained from the ester: —



$$\begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>C(COOH)_2 = \begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>CHCOOH + CO_2$$

As other classes of compounds are prepared from acids, and as the malonic ester synthesis furnishes evidence of the structure of acids prepared through its aid, the synthesis has been of great service in the building up of compounds, and in the determination of structure.

In carrying out the preparation of acids in this way the sodium derivatives of malonic ester are first prepared by adding the ester to the calculated weight of sodium ethylate dissolved in alcohol. A reaction takes place according to the equation, —

$$CH_2(COOC_2H_5)_2 + C_2H_5ONa = CHNa(COOC_2H_5)_2 + C_2H_5OH$$

The halide is now added and the mixture boiled until the solution becomes neutral. Addition of the mixture to water causes the solution of the sodium halide formed and the precipitation of the ester produced by the reaction.

Esters of Polyatomic Alcohols. Fats

135. The most important members of this class of compounds are the so-called *glycerides*, which are esters of glycerol, for example $(C_{15}H_{31}COO)_3C_3H_5$. The *fats* and *vegetable oils* are mixtures of esters, which on hydrolysis yield glycerol and homologues of acetic acid together with oleic acid and small amounts of other unsaturated acids. The glycerides composing the greater part of the fats and oils of commercial importance, are those of butyric, lauric, palmitic, stearic, oleic, linoleic, and ricinoleic acids. In addition, some fats contain, in relatively small proportions, the glycerol esters of caproic, caprylic, crotonic, and myristic acids.

The fats and oils obtained from various sources differ from one another in the proportion of the several esters present in each. This difference in composition results in a difference in physical properties, such as specific gravity, vicosity, index of refraction, and melting-point. All the fats and vegetable oils are soluble in ether, however, — a fact made use of in the analysis of foods to separate fats from the other constituents of food-products. As the physical properties of a fat or an oil obtained from a definite source are more or less constant, the determination of these properties is of value in the analysis of such substances. The chemical analysis of fats and oils is based upon determinations of the proportions of unsaturated compounds present, of the relation between the acids of low and high molecular weight obtained on hydrolysis, and of the proportion of substances which do not undergo hydrolysis. This statement will be made clearer by a brief consideration of a few of the more important methods employed in the analysis of fats and oils.

136. Iodine Value. — It will be recalled that unsaturated compounds unite directly with halogens and form addition-products. As the glycerides of the unsaturated acids enter into combination with iodine, the amount of the halogen which reacts when a definite weight of fat or oil, dissolved in chloroform, is treated with an alcoholic solution of iodine, is a measure of the extent to which unsaturated compounds are present. The reaction takes place more readily in the presence of mercuric chloride, which acts as a catalytic agent. The number obtained by dividing the weight of iodine which reacts by the weight of the oil used, and multiplying by 100, is called the iodine value. It is evident that if an oil contain much olein its iodine value will be high, while one containing a small proportion of unsaturated compounds will give a correspondingly small iodine value. Thus, cotton-seed oil has 111 — 116 as its iodine value, while that of cocoanut oil is 8.5 — 9. *The Elaidin Test*, which has already been mentioned (**101**), is also a measure of the unsaturation of the fat or oil.

The Reichert-Meissl Number of an oil is determined by the percentage of acids, soluble in water and volatile with steam, which is obtained when the fat is hydrolyzed. The method of analysis consists in saponifying a definite weight of fat with an alcoholic solution of sodium hydroxide, distilling off a definite volume of the solution after adding dilute sulphuric acid, and, finally, determining by titration the amount of acid in the filtered distillate. The number of cubic centimeters of tenth-normal alkali required to neutralize the soluble acids volatile with steam, which are obtained from 5 grams of the fat or oil, is called its Reichert-Meissl number. Of the fatty acids only those of low molecular weight are soluble in water and volatile with steam. The common fats differ in the proportion in which the glycerides of these acids are present. Thus the Reichert-Meissl number of butter-fat is 22 — 30, while that of lard is less than 0.5.

The Hehner Value expresses the relation between the insoluble and soluble acids obtained from the fat by hydrolysis.

The estimation of the *unsaponifiable matter* in certain oils is frequently of value. Most fats and oils contain substances which are not changed when heated with a solution of an alkali. As glycerides are converted by this treatment into glycerol and sodium salts of acids, substances soluble in water, the percentage of the material present which does not undergo hydrolysis can be determined. The presence of paraffin, mineral oils, and other hydrocarbons can be determined by this test. Certain solid alcohols are present in some animal fats and edible oils. As they are not affected by a solution of sodium hydroxide they are obtained along with other unsaponifiable matter. The alcohols which occur most frequently are cholesterol, $C_{27}H_{43}OH$, which is present in wool-grease and is used in pharmacy under the name lanolin in the preparation of ointments, phytosterol — a constituent of certain vegetable oils — and sitosterol, which is present in some cereals. Phytosterol and sitosterol appear to be isomers of cholesterol; the structures of the three alcohols are not known.

137. A few fats and oils will be described briefly as examples. *Cottonseed oil* is obtained from the seeds of the cotton plant. It contains stearin, palmitin, olein, and linolein. It is used for cooking purposes, as a salad oil, in the manufacture of soap, as an adulterant for olive oil, butter, and lard, and in the manufacture of butter substitutes. The iodine value of the refined oil is 111 – 116.

Olive oil, which is obtained from the fruit of the olive tree, contains about 28 per cent of solid fat consisting of palmitin and a little arachidin. The rest is mostly olein. Substances present in smaller quantities are linolein, cholesterol, free fatty acids, and unsaponifiable matter. The oil is used as a salad oil, as a lubricant, in soap stock, and for other purposes. Its iodine value is 77 – 88. The elaidin test produces a solid mass within two hours. On account of its high cost it is frequently adulterated with cottonseed, peanut, lard, and other oils.

Cod-liver oil, obtained from the liver of the codfish, is an example of a fish oil. It contains the glycerides of oleic, myristic, palmitic, and stearic acids, some volatile fatty acids, and some cholesterol. Traces of iodine and phosphorus are also present. The oil is used in medicine. The fact that it is so readily digested and assimilated is probably due to the presence in it of bilary compounds. It is frequently adulterated with other fish oils.

Lard is prepared from the fat of the hog. It consists of stearin, palmitin, and olein, with a small amount of linolein. Fresh lard contains but a small amount of free acid (0.1 to 0.4 per cent). On exposure to the air partial decomposition takes place and the acidity increases. The iodine value of old lard is less than that of the fresh substance.

Tallow is the solid fat of the sheep or ox. It consists of almost two-thirds palmitin and stearin, and one-third olein. It is extensively used for soap and candle stock, for lubricating, and as a dressing for leather.

Butter is a mixture of fat, water, curd, milk-sugar, and salts. The amount of fat varies between 78 and 94 per cent. Butter-fat differs from other animal fats in that it contains an appreciable proportion of glycerides of the fatty acids of low molecular weight. It contains about 60 per cent olein, 30 per cent palmitin and stearin, and 5 per cent butyrin. Small amounts of the glycerides of capric, caprylic, myristic, and other acids are present. Butter-fat, on account of the comparatively high percentage of volatile acids which it contains, gives a large Reichert-Meissl number, 22 to 30. Butter is usually colored by the addition of carrot juice, turmeric, or annatto; synthetic coal-tar dyes are also used at times. The rancidity of butter is produced as the result of bacterial action, by which butyric and other acids having a disagreeable odor and taste are produced.

Oleomargarine and other butter-substitutes are made from mixtures of animal and vegetable oils. The olein from tallow, lard, or cottonseed oil is frequently used. These are colored and mixed with a small proportion of butter, or churned with milk in order to give the product the appearance and taste of butter. Oleomargarine can be distinguished from butter by the determination of the Reichert-Meissl number of each. That of the former is seldom more than 1, while that of butter is from 22 to 30.

WAXES

138. The waxes consist essentially of esters of the higher saturated monatomic alcohols and the higher fatty acids. *Sperm oil* is a liquid wax obtained from the blubber and head cavity of the sperm whale. It contains no glycerides, but probably consists of the esters of dodecatyl alcohol, $C_{12}H_{25}.OH$, cetyl alcohol, $C_{16}H_{33}.OH$, and other saturated alcohols. It is used as an illuminant, for leather dressing, and in the tempering of steel.

Spermaceti, which is a crystalline wax obtained from sperm oil, consists mainly of cetyl palmitate, $C_{15}H_{31}COOC_{16}H_{33}$. It is used in candle-making, in confectionery, and in perfumery.

Bees-wax is obtained from the honey-comb of bees; it consists chiefly of the palmitic ester of myricyl alcohol, $C_{15}H_{31}COOC_{30}H_{61}$. Some cerotic acid, $C_{26}H_{53}COOH$, is also present in the wax. It finds many uses in the arts.

Carnauba wax is an example of a vegetable wax. It forms as a coating on the leaves of a species of palm. It contains, among other substances, myricyl alcohol, $C_{30}H_{61}OH$, cerotic acid, $C_{26}H_{53}COOH$, and myricyl cerotate. It is used for candle-making, in varnishes, and for adulterating bees-wax.

139. Properties of Esters of Analytical Significance. — The property of esters which is most frequently made use of in their identification is their ability to undergo hydrolysis. All esters are converted into alcohols and sodium salts of acids when heated with an aqueous solution of sodium hydroxide. When the hydrolysis has been effected, the mixture is distilled, if the alcohol formed is soluble and volatile with steam. The alcohol is obtained by saturating the distillate with potassium carbonate. The layer which separates is dried over lime and distilled. If an insoluble alcohol is formed, it is separated, dried, and distilled. The acid formed from the ester can be isolated by precipitation from its sodium salt with hydrochloric acid, if it is insoluble in water. If soluble, the solution of its salt is evaporated to dryness, and the residue distilled with concentrated sulphuric acid. The physical properties of the ester, together with those of the alcohol or acid derived from it, serve to identify it. Hydrolysis of esters is often carried out in alcoholic solution in the case of those which are soluble in alcohol, as reaction takes place more quickly when the reacting substances are in solution.

Many esters are soluble in cold concentrated sulphuric acid. This property serves to distinguish them from hydrocarbons, alkyl halides, and many other compounds.

Some esters react with sodium with the evolution of hydrogen when they are treated with the metal. Ethyl acetate undergoes a profound change when heated with sodium. The fact is mentioned here as it has been pointed out that sodium is frequently used in testing for the presence of a hydroxyl group in organic compounds. As simple esters do not contain this group, it is seen that the formation of hydrogen when a compound is treated with sodium is not positive evidence that a hydroxyl group is present. Notwithstanding this limitation, the test is a valuable one, and is frequently used in the investigation of substances of unknown structure. Most esters are liquids or solids, which are insoluble in water, and have specific gravities less than one.

PROBLEMS

1. Summarize, in the form of equations, the methods which can be used to prepare ethers, esters, and anhydrides. Write equations for the characteristic reactions of the three classes of compounds.

2. How could you distinguish by chemical test from one another the following: (*a*) $(C_3H_7)_2O$, $C_3H_7COOC_3H_7$, and $(C_3H_7CO)_2O$, (*b*) C_3H_7OH and $(C_3H_7)_2O$, (*c*) $CH_3.CHOH.COOC_2H_5$ and $CH_3.CHOC_2H_5.COOH$, (*d*) $(C_4H_9)_2O$ from C_8H_{18}?

3. Write equations for the reactions which take place when the methyl ester of α-ethoxy-propionic acid is heated with (*a*) a solution of sodium hydroxide, and (*b*) with a concentrated aqueous solution of hydriodic acid.

4. How could you separate, without the use of fractional distillation (*a*) ether from ethyl bromide, (*b*) ethyl acetate from petroleum ether, (*c*) palmitic acid from octyl ether?

5. Show how acids of the following structure may be prepared by means

of the malonic ester synthesis: (*a*) $CH_3CH_2CH_2.COOH$, (*b*) $C_2H_5.C_3H_7.CH.COOH$. (*c*) $CH_3CH_3CH.CH(COOH)_2$, (*d*) $CH_3.CH_3.C:(COOH)_2$.

6. Show how isopentane may be prepared from methyl iodide, isopropyl iodide, and malonic ester.

7. How could you distinguish beeswax from a solid fat?

8. Would more or less sodium hydroxide be required to saponify 5 grams of butter than to saponify 5 grams of lard? Give reason for the answer, and show how a quantitative study of saponification could be made the basis of a method for the analysis of fats.

CHAPTER X

ALDEHYDES AND KETONES

140. In the discussion of alcohols it was noted that they are converted by active oxidation into acids. By careful regulation of the process, however, intermediate compounds are obtained in the case of primary and secondary alcohols. The reactions in the case of primary alcohols may be illustrated by the equations which express the oxidation of ethyl alcohol: —

$$C_2H_6O + O = C_2H_4O + H_2O$$
$$C_2H_4O + O = C_2H_4O_2$$

The first change consists in the removal of two hydrogen atoms and the formation of a substance which is known as an aldehyde (from *al*cohol *dehyd*rogenatus). Addition of oxygen converts the aldehyde into an acid with the same number of carbon atoms.

In the case of a secondary alcohol, the first step brings about a change similar to that which takes place when a primary alcohol is oxidized. The oxidation of isopropyl alcohol — the secondary alcohol which contains the smallest number of carbon atoms — is represented by the equation, —

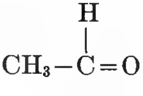
$$C_3H_8O + O = C_3H_6O + H_2O$$

The substance formed in this case is called acetone, which belongs to the class of compounds known as ketones. Further oxidation of acetone and other ketones brings about a complete disintegration of the molecule and the formation of acids which contain a smaller number of carbon atoms than the ketone from which they were formed.

In the formation of both aldehydes and ketones by oxidation, the change consists in the removal of two hydrogen atoms; a similarity in structure of the two classes of compounds, and, as a consequence, in their reactions might be expected. Such similarity does exist. In the determination of the structure of these substances the manner in which the oxygen atom is linked to carbon is first to be examined. The substances do not show the properties of alcohols or acids, and, therefore, do not contain a hydroxyl group. The composition of the compounds formed when aldehydes and ketones are treated with phosphorus pentachloride furnishes positive information which leads to an understanding of the structure of members of these classes. The equations for the reactions in the two cases are: —

$$C_2H_4O + PCl_5 = C_2H_4Cl_2 + POCl_3$$
$$C_3H_6O + PCl_5 = C_3H_6Cl_2 + POCl_3$$

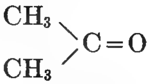
In both cases one atom of oxygen is replaced by two atoms of chlorine. It is evident from this that the oxygen is not present in the compounds in the form of a hydroxyl group, for in this case the oxygen is joined to carbon by a single bond $(C-O-H)$ and when replaced by chlorine but one atom of the latter can remain in combination with carbon. Further, in the replacement of hydroxyl oxygen by chlorine, hydrogen is simultaneously removed. As in the reactions given above a single oxygen atom is replaced by two chlorine atoms, it seems most probable that the former is held in combination with carbon by two bonds in both aldehydes and ketones, and that these substances contain the carbonyl group $(C=O)$. Granted this as true, the structure of aldehyde and acetone can be expressed by the formulas, —



$$CH_3-\overset{\overset{\large H}{|}}{C}=O$$

aldehyde

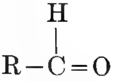
and



$$\begin{array}{l} CH_3\diagdown \\ \qquad\quad C=O \\ CH_3\diagup \end{array}$$

acetone

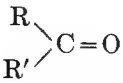
It will be shown in the detailed discussion of these compounds that their properties can best be interpreted through the use of these formulas. The general formulas for members of these classes are: —



$$R-\overset{\overset{\large H}{|}}{C}=O$$

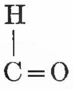
aldehydes

and

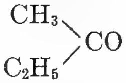


$$\begin{array}{l} R\diagdown \\ \quad\; C=O \\ R'\diagup \end{array}$$

ketones

The relation between aldehydes and ketones is clear when their structure is expressed in this way. They are alike in containing a carbonyl group; they differ in that aldehydes contain one radical and one hydrogen united to this group, while in the case of ketones two radicals are present. It appears from the formulas that the two classes of compounds should be considered as members of the same homologous series since they bear to each other a relation similar to that between formic and acetic acids ($H.COOH$ and $CH_3.COOH$). As some characteristic reactions of aldehydes which are not shown by ketones are brought about as the result of the presence in aldehydes of the hydrogen atom in combination with the carbonyl group, compounds which contain the group  $\overset{\overset{H}{|}}{C}=O$ are treated as a class by themselves. In the study of the properties of aldehydes and ketones, the student should continually keep in mind the relation between the two classes of compounds which has been pointed out.

141. Nomenclature of Aldehydes and Ketones. — The aldehydes are usually named from the acids into which they pass on oxidation, thus $CH_3.CHO$ is acetic aldehyde or acetaldehyde, as it is converted by oxidizing agents into acetic acid. In another system of nomenclature the name of an aldehyde is formed by adding the syllable *al* to the name of the hydrocarbon which contains the same number of carbon atoms as the aldehyde. According to this system acetaldehyde is called ethanal.

The name of a ketone is determined by the radicals which are in combination with the carbonyl group. Thus, the substance with the structure  $\begin{matrix} CH_3 \searrow \\ \quad CO \\ C_2H_5 \nearrow \end{matrix}$ is called methyl-ethyl ketone. The names of ketones, according to the newer system, are formed by adding the termination *one* to the name of the hydrocarbon which contains the same number of carbon atoms as the ketone. A number is added to express the position of the carbon of the carbonyl group in relation to the end carbon atom of the chain; thus, diethyl ketone, $CH_3CH_2.CO.CH_2CH_3$, is pentanone-3.

ALDEHYDES

142. Formaldehyde, H.CHO, is the simplest aldehyde. It is a gas, which is soluble in water, and has a powerful, irritating odor. It can be condensed to a liquid that boils at −21°. Formaldehyde is formed as the result of the oxidation of methyl alcohol. It is usually prepared by passing a mixture of air and the vapor of methyl alcohol over heated copper. The mixture is obtained by drawing air through the alcohol which is heated to 40°–50°. After the reaction begins, sufficient heat is evolved as the result of the oxidation to keep the copper, which is conveniently in the form of a spiral of gauze, in a glowing condition. The gases produced are condensed, and a liquid is formed which contains water, methyl alcohol, and formaldehyde. By proper regulation of the process a product can be obtained which contains 40 per cent aldehyde. Such a solution is sold under the name "formalin." It is used as a disinfectant and food preservative, and in the manufacture of certain dyes. Anatomical specimens may be preserved by keeping them in a solution of formaldehyde. As the aldehyde hardens albuminous substances, it is used in the preparation of tissues in histological work, and as it converts gelatin into a hard insoluble substance, it is frequently used to harden the films on photographic plates.

Formaldehyde is produced abundantly when methyl alcohol burns in an amount of air which is insufficient for its complete combustion. Special forms of lamps have been devised in which methyl alcohol is burned under these conditions. They are used for disinfecting purposes.

Formaldehyde is readily oxidized, formic acid and carbon dioxide being formed. When a few drops of a solution containing the aldehyde are added to an ammoniacal solution of silver nitrate, the metal is deposited in the form of a mirror on the sides of the containing vessel. It also reduces the salts of other metals to the metallic conditions; for example, a solution of mercuric chloride is reduced to mercurous chloride and, finally, to mercury.

In dilute alkaline solution formaldehyde is oxidized quantitatively to a formate by hydrogen peroxide. The percentage of formaldehyde in commercial formalin can be determined through the use of this reaction, which is represented by the equation, —

$$H.CHO + NaOH + H_2O_2 = H.COONa + 2H_2O$$

An excess of hydrogen peroxide and of a solution of sodium hydroxide of known strength is added to the dilute solution of formalin. The excess of alkali is determined by titration with an acid, and from the amount of sodium hydroxide used in the reaction the weight of aldehyde can be calculated.

Formaldehyde can be reduced by nascent hydrogen to methyl alcohol: —

$$H.CHO + 2H = CH_3.OH$$

As all aldehydes take part in a similar reaction it is possible to pass readily from an aldehyde to an alcohol by reduction.

When an aqueous solution of formaldehyde is treated with ammonia, reaction takes place with the formation of a substance of complex structure possessing weakly basic properties, called hexamethylene amine: —

$$6H.CHO + 4NH_3 = (CH_2)_6N_4 + 6H_2O$$

The action of this aldehyde with ammonia is unique, as other substances of this class form well characterized addition-products which consist of one molecule of each constituent.

In aqueous solution in the presence of sodium hydroxide, formaldehyde reacts with water, and formic acid and methyl alcohol are produced: —

$$2HCHO + H_2O = CH_3OH + H.COOH$$

In this reaction, also, formaldehyde differs from its homologues, which are converted into resin-like substances by alkalies.

Polymerization of formaldehyde takes place with great readiness. The liquid aldehyde slowly polymerizes at its boiling-point (–21°). When an aqueous solution is evaporated over concentrated sulphuric acid, or by heat, only a part of the aldehyde escapes as a gas; the rest is left as a white crystalline mass which, after sublimation, melts at 171°–172° and is insoluble in water. The molecular weight of the substance which is called *oxymethylene* or *metaformaldehyde*, is not known. Its composition is expressed by the formula $(CH_2O)_x$. Oxymethylene is converted into formaldehyde when heated or when it is boiled with water. It is sold in the form of tablets or candles under the name "paraform," and is used for disinfecting purposes, as it serves as a convenient source of formaldehyde.

When a dilute aqueous solution of formaldehyde which is saturated with calcium hydroxide, is allowed to stand for several days, polymerization of the aldehyde takes place and a mixture of substances, called formose, is obtained; the product shows the characteristic reactions of the sugars. From this mixture Emil Fischer isolated a compound, called acrose, which has the same empirical formula as glucose, $C_6H_{12}O_6$, and which resembles closely the sugars occurring in nature. The view has been put forward that formaldehyde plays an important part in the building up in plants of the carbohydrates, such as sugar, starch, and cellulose. Plants build up these substances from water and the carbon dioxide in the air. It seems probable that the process consists in the reduction to formaldehyde of carbon dioxide in the presence of water, sunlight, and the chlorophyl in leaves, and that the aldehyde then undergoes polymerization with the production of carbohydrates. The hypothetical reactions may be represented by the equations, —

$$CO_2 + H_2O = H.CHO + O_2$$
$$6H.CHO = C_6H_{12}O_6$$

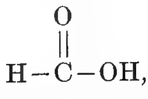
143. Tests for Formaldehyde. — As formaldehyde is much used as a preservative, many special tests have been devised for its detection when present in minute quantities. One of the simplest is that employed in the investigation of the presence of formaldehyde in milk. The test is carried out by diluting the milk with an equal volume of water, adding a few drops of a solution of ferric chloride, and pouring concentrated sulphuric acid slowly into the mixture so that two layers are formed. If formaldehyde is present, a violet ring forms at the juncture of the liquids when the vessel containing them is immersed in hot water. The test will show the presence of one part of formaldehyde in 200,000 parts of milk. The production of the color is the result of a reaction between the aldehyde and a constituent of the milk. Any solution may be tested for the aldehyde by mixing it with milk and proceeding in the manner described. Other color reactions are frequently used.

A convenient test which may be used to detect small quantities of formaldehyde is made as follows: To about one cubic centimeter of the solution of the aldehyde, which has been diluted to such a concentration that its odor is barely perceptible, is added one drop of a one-half per cent aqueous solution of resorcinol (**450**). The mixture so prepared is poured slowly down the side of a test-tube containing about 5 cc. of concentrated sulphuric acid in such a way that the two liquids do not mix. A red ring soon appears at the juncture of the two liquids, and a white flocculent precipitate, which changes to red, forms in the aqueous layer.

144. Acetaldehyde, $CH_3.CHO$, is a typical member of the homologous series of aldehydes, which can be prepared from the saturated alcohols. The methods by which it may be formed and its reactions with other substances are more representative of the group than those of formaldehyde. It will be recalled that formic acid, the first member of the fatty acid series, differs markedly in some of its reactions from acetic acid and the other members of the series. The same relations have been observed in the case of the first members of other homologous series. Acetaldehyde is a liquid which is miscible with water in all proportions, and possesses a marked, characteristic odor. It boils at 21° and solidifies at $-120.6°$. It is prepared by oxidizing ethyl alcohol. A mixture of alcohol, sulphuric acid, and water is allowed to drop slowly onto powdered potassium bicromate contained in a flask provided with a condenser. Reaction soon takes place, and a distillate is obtained which contains aldehyde, alcohol, and small quantities of other substances. On slow redistillation, care being taken to collect only the part which boils below 35°, aldehyde containing only a small amount of water is obtained. The final purification is effected by distillation, after drying with calcium chloride.

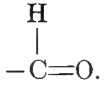
Aldehyde is formed when a salt of acetic acid is heated with a formate: —

$$\begin{array}{r|l} \mathrm{CH_3} & \mathrm{COONa} \\ \overline{\mathrm{HCO}} & \mathrm{ONa} \end{array} = CH_3.CHO + Na_2CO_3$$

The structure assigned to formic acid,  $H-\overset{\overset{\displaystyle O}{\|}}{C}-OH$, indicates that it contains an aldehyde group. Some of its reactions are in accord with this view of its structure. It will be recalled that it is oxidized with great ease. It reduces an ammoniacal solution of silver nitrate, and thus takes part in a reaction which is of great value in the identification of aldehydes. The reaction which takes place when a formate is heated with a salt of acetic acid is one of importance, on account of the fact that it is an example of a general reaction which can be applied in the preparation of other members of this class. When the salt of an acid is heated with a formate, the corresponding aldehyde is obtained. Calcium salts are commonly used as the yield of aldehyde is greater than that obtained when salts of the alkali metals are employed.

Aldehyde is formed by the direct removal of hydrogen from alcohol. This can be effected by passing the vapor of alcohol over finely divided copper obtained by the reduction of copper oxide. When the temperature is maintained at 250°–400° direct decomposition of the alcohol takes place according to the equation, — $C_2H_6O = C_2H_4O + H_2$.

The Reactions of Aldehyde are, in general, typical of the substances which contain the group

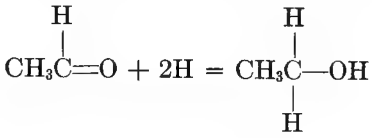


$-\overset{H}{\overset{|}{C}}=O$.

They are best explained on the assumption that aldehyde contains a group of this configuration, and serve to strengthen the conclusion arrived at from the study of the action of phosphorus pentachloride upon aldehyde.

The hydrogen atom in combination with the carbonyl group ($C=O$), can be readily oxidized. When a solution containing aldehyde is mixed with an ammoniacal solution of silver nitrate, a silver mirror is formed. Gentle heat and the presence of a few drops of a solution of potassium hydroxide facilitate the reduction of the silver salt. The caustic alkali should be added to the ammoniacal solution just before use, as such a solution deposits, on standing in the presence of sodium or potassium hydroxide, a substance which may suddenly undergo decomposition with explosive violence.

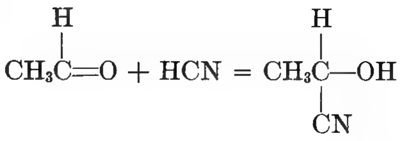
The most characteristic reactions of aldehydes are those in which they form addition-products with other substances, and those in which polymers are formed as the result of the direct combination of two or more molecules of the aldehyde. These reactions are the result of the presence of the carbonyl group (C=O) in aldehydes. Aldehyde is reduced to alcohol when treated in aqueous solution with sodium amalgam. The reduction consists in the addition of two hydrogen atoms to the molecule. This addition is made possible by the breaking of the double bond between the carbon and oxygen atoms: —



$$\mathrm{CH_3\overset{\overset{H}{|}}{C}{=}O + 2H = CH_3\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}{-}OH}$$

The nature of the union between carbon and oxygen in the carbonyl group in aldehydes resembles somewhat that between the unsaturated carbon atoms in ethylene. In both cases saturated addition-products can be formed as the result of the addition of other atoms or molecules.

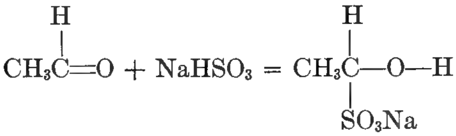
Aldehyde and hydrocyanic acid unite and form a substance which has been shown to be the nitrile of α-hydroxypropionic acid. The addition must, therefore, take place according to the equation, —



$$\mathrm{CH_3\overset{\overset{H}{|}}{C}{=}O + HCN = CH_3\underset{\underset{CN}{|}}{\overset{\overset{H}{|}}{C}}{-}OH}$$

In the union of the two molecules, the positive hydrogen atom of the hydrocyanic acid enters into combination with the negative oxygen atom, and the negative CN radical with the more positive carbon atom. This action in addition is an example of a general principle which applies to many such reactions. When two molecules interact there is a tendency for the reaction to take place in such a way that the more positive part of one unites with and tends to neutralize the more negative part of the other.

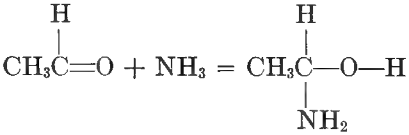
When aldehyde is shaken with a saturated solution of sodium hydrogen sulphite, addition takes place and a crystalline compound is obtained: —



$$\mathrm{CH_3\overset{H}{\overset{|}{C}}{=}O + NaHSO_3 = CH_3\underset{SO_3Na}{\underset{|}{\overset{H}{\overset{|}{C}}}}{-}O{-}H}$$

When heated with an acid the addition-product is decomposed and the aldehyde is set free. As the corresponding derivatives of many other aldehydes crystallize from water, the formation of such derivatives is frequently taken advantage of in the isolation of aldehydes and in their purification from other substances.

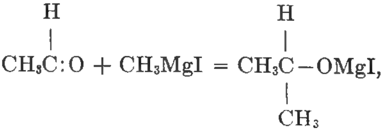
Aldehyde combines directly with ammonia to form a compound called aldehyde ammonia. It is usually prepared by passing gaseous ammonia and the vapor of aldehyde into dry ether, which is kept cold. The compound separates as well formed crystals. Addition takes place according to the equation, —



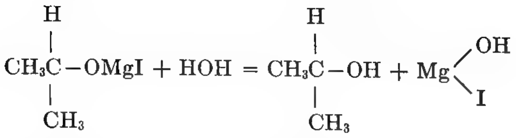
$$\mathrm{CH_3\overset{H}{\overset{|}{C}}{=}O + NH_3 = CH_3\underset{NH_2}{\underset{|}{\overset{H}{\overset{|}{C}}}}{-}O{-}H}$$

As aldehyde is formed when aldehyde ammonia is warmed with a dilute acid, the substance can be used in the preparation of pure aldehyde.

Aldehydes form addition-products with the magnesium alkyl halides, from which secondary alcohols may be obtained by decomposition with water. These reactions have been much used in the preparation of alcohols of this class. The reactions are indicated by the following equations: —



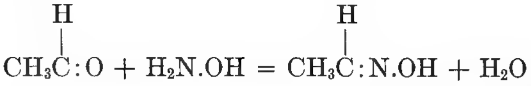
$$\mathrm{CH_3\overset{H}{\overset{|}{C}}{:}O + CH_3MgI = CH_3\underset{CH_3}{\underset{|}{\overset{H}{\overset{|}{C}}}}{-}OMgI,}$$



$$CH_3\overset{H}{\underset{CH_3}{C}}-OMgI + HOH = CH_3\overset{H}{\underset{CH_3}{C}}-OH + Mg\begin{smallmatrix}OH\\ I\end{smallmatrix}$$

It will be noted that in the addition of the magnesium alkyl halide, the positive metallic atom remains in combination with the halogen atom and unites with the oxygen of the aldehyde, while the alkyl group joins itself to carbon. The way in which the union takes place should be noted, as the magnesium alkyl halides are much used in synthetic work, and in the formation of addition-products with compounds containing oxygen, the union takes place in a manner similar to that just explained.

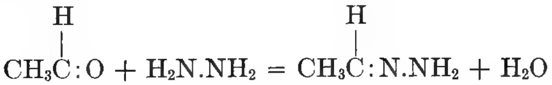
145. Aldehydes enter into important reactions of another type. The reaction with hydroxylamine is an example. When an aldehyde is warmed with an aqueous solution of this reagent a substance is formed which belongs to the class known as *aldoximes*. Acetaldehyde gives *acetoxime;* —



$$CH_3\overset{H}{C}:O + H_2N.OH = CH_3\overset{H}{C}:N.OH + H_2O$$

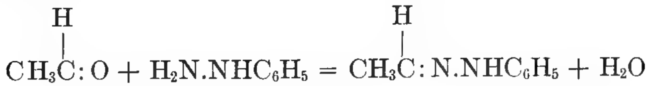
As many aldoximes have well defined physical properties they are of service in the identification of aldehydes. The aldoximes are hydrolyzed when boiled with dilute hydrochloric acid.

A reaction of similar nature takes place between aldehydes and hydrazine: —



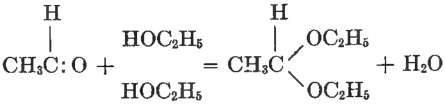
$$CH_3\overset{H}{C}:O + H_2N.NH_2 = CH_3\overset{H}{C}:N.NH_2 + H_2O$$

The compounds formed, called *hydrazones*, can be hydrolyzed by boiling with a dilute acid. In the identification of aldehydes, the physical properties of the hydrazone prepared from the aldehyde and phenylhydrazine, $C_6H_5HN.NH_2$, are frequently determined. The reaction in this case is analogous to that with hydrazine: —



$$CH_3\overset{H}{C}:O + H_2N.NHC_6H_5 = CH_3\overset{H}{C}:N.NHC_6H_5 + H_2O$$

146. Substances called *acetals* are prepared by a reaction which resembles somewhat those just described. When acetaldehyde is heated with alcohol in the presence of acetic acid or a small amount of hydrogen chloride or sulphuric acid, acetal is formed: —

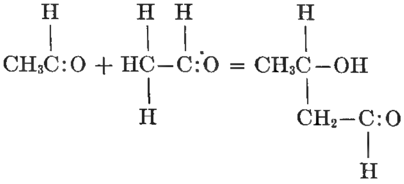


$$\begin{array}{c}H\\|\\CH_3C:O\end{array}+\begin{array}{c}HOC_2H_5\\ \\HOC_2H_5\end{array}=\begin{array}{c}H\\|\\CH_3C\end{array}\begin{array}{l}\diagup OC_2H_5\\ \\ \diagdown OC_2H_5\end{array}+H_2O$$

The methods of preparation of acetals recalls that of esters, but the compounds more closely resemble ethers in chemical properties. They are unaffected by alkalies, but are readily hydrolyzed by boiling with acids. Acetals are frequently used in syntheses in the place of the more active aldehydes. The substances formed from the two classes of substances in such syntheses are the same.

147. The Polymerization of Aldehyde is readily effected. When aldehyde is warmed with a strong solution of an alkali, the solution becomes yellow in color and a resin-like substance precipitates. This is called *aldehyde-resin*. Its structure is not known. It is, however, a polymer of aldehyde. It will be remembered that formaldehyde is not converted into a resin in this way. The reaction is, however, characteristic of other aldehydes.

When acetaldehyde is treated with a dilute solution of an alkali or certain salts, such as sodium acetate and zinc chloride, a polymer is formed, which consists of two molecules of aldehyde in combination with each other. This substance, called *aldol*, is a liquid which boils without decomposition under diminished pressure, and readily undergoes further polymerization. Aldol shows the reactions which are characteristic of aldehydes and can be converted by oxidation into β-hydroxybutyric acid. These facts are evidence that aldol is the aldehyde of this acid. The union of the aldehyde molecules to form aldol is, therefore, best represented by the equation, —



$$\begin{array}{c}H\\|\\CH_3C:O\end{array}+\begin{array}{c}H\quad\ H\\|\quad\ \ |\\HC-C:O\\|\qquad\ \\H\qquad\ \end{array}=\begin{array}{l}\qquad\ H\\ \qquad\ |\\CH_3C-OH\\ \qquad\ |\\ \qquad\ CH_2-C:O\\ \qquad\qquad\quad\ \ |\\ \qquad\qquad\quad\ \ H\end{array}$$

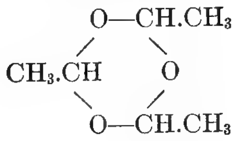
If this view is correct, — and the properties of aldol are in accord with the structure given, — the union takes place in a way which is entirely analogous to that between aldehyde and hydrocyanic acid, ammonia, or sodium hydrogen sulphite. In all these cases one hydrogen atom enters into combination with the oxygen of the carbonyl group, and the rest of the compound unites with the carbon atom of this group. According to this view aldol contains an aldehyde group, and, as a consequence, its reactions, which are those of an aldehyde, are readily understood.

Aldol loses water when heated with a solution of sodium acetate and forms crotonic aldehyde: —

$$CH_3.CHOH.CH_2.CHO = CH_3.CH{:}CH.CHO + H_2O$$

Substances of these types are readily obtained from aldehydes. As a consequence the so-called aldol condensation is frequently made use of in synthetic organic chemistry. By *condensation* is meant the union of two or more of the same or different molecules, with or without the elimination of water or some other inorganic compound. The term is sometimes restricted to include only those reactions in which carbon unites with carbon, and compounds are formed which can not be readily decomposed into the substance or substances from which they were prepared.

148. In the presence of acids the polymerization of aldehydes yields substances of a different nature. When aldehyde is treated with a drop of concentrated sulphuric acid, polymerization immediately takes place with the evolution of sufficient heat to cause violent boiling. The product formed, called *paraldehyde*, is a colorless liquid with characteristic odor, which boils at 124°, and after solidification melts at 10.5°. It is soluble in about eight volumes of water and has the specific gravity 0.994 at 20°. The molecular weight of paraldehyde, calculated from its vapor density, corresponds to that expressed by the formula $(C_2H_4O)_3$. Paraldehyde shows none of the reactions characteristic of aldehydes. It does not, therefore, contain the aldehyde group. As it is converted into aldehyde when heated with dilute solutions of mineral acids, it is probable that in its formation the addition of the three molecules of aldehyde into one molecule is effected through the oxygen atoms, and not through the union of carbon atoms with each other. The structure assigned to paraldehyde is, —



This view is based on the fact that the study of many compounds has shown that the breaking of the bond between two carbon atoms is, in most cases, accomplished with difficulty, whereas compounds in which carbon atoms are united through an oxygen atom are decomposed with more or less ease. For example, hydrocarbons and the alkyl radicals which they contain are very stable, whereas esters, ethers, and other compounds in which oxygen serves as a link in holding the atoms together, can be decomposed by various reagents. It is important to note that in these decompositions the bond between oxygen and carbon is broken and not that between two carbon atoms.

If the polymerization of acetaldehyde is brought about by acids at a low temperature, a solid polymer which is isomeric with paraldehyde is formed. The substance is called *metaldehyde.* It separates in fine needles when a trace of hydrogen chloride, sulphur dioxide, or dilute sulphuric acid is added to well cooled aldehyde. Metaldehyde is insoluble in water, sublimes with partial decomposition into aldehyde when rapidly heated, and shows none of the reactions characteristic of aldehydes. It is metameric with paraldehyde of which it is supposed to be a steroisomer.

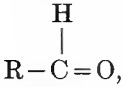
The polymerization of aldehydes is a reaction which, in all probability, plays an important part in life processes. The view of the role of formaldehyde in the growth of plants has already been mentioned. Experiments on protoplasm indicate that aldehydes are involved in the building up of cells. Living cells reduce an ammoniacal solution of silver nitrate, and show other reactions characteristic of aldehydes. Dead cells, on the other hand, show none of these reactions. It is of interest in this connection that hydroxylamine, phenyhydrazine, and other substances which react readily with aldehydes are powerful poisons, especially for the lower organisms.

Chlorine and bromine replace the hydrogen atoms of the methyl group in aldehyde, when the latter is treated with the halogens. The ease with which the replacement takes place is markedly affected by the presence of the aldehyde group. While the hydrogen atoms of the methyl group in acetic acid and in most hydrocarbons are replaced slowly by halogen, even when heated in the presence of sunlight, the corresponding substitution in the case of aldehydes takes place rapidly at ordinary temperatures. The final product of the action of chlorine on aldehyde is chloral, $CCl_3.CHO$.

149. Structure of Aldehyde. — It has been seen how the reactions into which aldehyde enters can be explained on the assumption that the structure of its molecule is that which has been assigned to it. The conversion of aldehyde into dichlorethane of the structure $CH_3.CHCl_2$ is strong evidence that the oxygen which is present in aldehydes is joined to a single atom of carbon. The fact that aldehyde may be prepared by heating ethylidene chloride with water, —

$$CH_3.CHCl_2 + H_2O = CH_3.CHO + 2HCl$$

is evidence that simple substitution has taken place.

150. Homologues of Acetaldehyde. — A number of members of an homologous series of aldehydes of the general formula  $R-\overset{H}{\overset{|}{C}}=O$, where R represents a saturated alkyl group, are known. The lower members (up to $C_{11}H_{22}O$) are liquids, which are lighter than water, distil without decomposition, and possess a more or less disagreeable odor. The lowest members are readily soluble in water, but the solubility rapidly decreases as the number of carbon atoms in the molecule increases. The higher aldehydes are colorless, waxy solids.

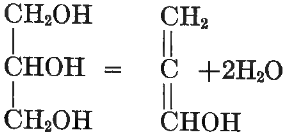
151. Properties of Aldehydes of Analytical Significance. — Two of the reactions of aldehyde which have been described are much used in the identification of members of this class of compounds, namely, the formation of a mirror when an ammoniacal solution of silver nitrate is gently warmed with an aldehyde, and the polymerization of the latter to a resin when heated with a strong solution of a caustic alkali. If these reactions take place when a substance is treated as described, there is a strong probability that it is an aldehyde. Compounds other than aldehydes, however, reduce an ammoniacal solution of silver salts, and other tests should be applied in addition to the ones just given. When an aqueous solution of rosaniline, which is a red dye, is treated with a saturated solution of sulphur dioxide in water, the color is destroyed. The colorless solution, known as *Schiff's reagent*, is of great value in testing for aldehydes. When a few drops of an aldehyde are added to about 5 cc. of the reagent, a red-violet color appears within a few seconds. The composition of the colored substance formed is not known.

Aldehydes reduce an alkaline solution of a cupric salt to cuprous oxide. The reagent used is called *Fehling's solution* (**252**). It is prepared by adding copper sulphate to a solution which contains sodium hydroxide and Rochelle salt, sodium potassium tartrate $(CHOH.COO)_2KNa$. In the presence of the tartrate copper hydroxide is not precipitated, and a clear, dark blue solution is obtained. When an aldehyde is warmed with Fehling's solution, cuprous oxide is formed as a precipitate, which is usually red. As certain substitution-products of ketones (**289**) reduce Fehling's solution, the test does not serve to identify aldehydes positively. It is, however, of service, and is much used in the study of carbohydrates, many of which contain aldehyde groups.

UNSATURATED ALDEHYDES

152. The chemistry of the unsaturated aldehydes resembles closely that of acetaldehyde. They may be prepared by the oxidation of unsaturated primary alcohols, and by the conversion of saturated aldehydes into unsaturated compounds by the application of the methods usually employed to establish a double bond in a compound. Certain members of this class occur in the so-called *essential oils*, — the volatile liquids which give the characteristic odors to plants. The composition of a number of these oils will be given later.

153. **Acrylic Aldehyde**, $CH_2{=}CH.CHO$, is the unsaturated aldehyde which contains the smallest number of carbon atoms. On account of the fact that it has a disagreeable penetrating odor, and affects the eyes strongly, producing a copious flow of tears, it was originally named acrolein (from *acer*, sharp, and *oleum*, oil) and is still often called by this name. Acrolein is a colorless liquid, which boils at 52.4°. It can be prepared by the oxidation of allyl alcohol, $CH_2{=}CH.CH_2OH$, but is obtained more readily by the removal of water from glycerol. The dehydration is best effected by heating glycerol with acid potassium sulphate. The removal of two molecules of water from glycerol should yield an alcohol with two double bonds if the reaction takes place normally: —



$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} = \begin{array}{l} CH_2 \\ \| \\ C \\ \| \\ CHOH \end{array} + 2H_2O$$

As acrolein is obtained, however, it is evident that if such an alcohol is formed it immediately undergoes a rearrangement, which results in the formation of the aldehyde.

Acrolein is formed when fats and oils, which it will be remembered are esters of glycerol, are heated to a high temperature. The pungent odor produced when a tallow candle is extinguished is probably due to the formation of acrolein. The reactions of acrolein are in accord with the structure assigned to it. It can be reduced to allyl alcohol and oxidized to acrylic acid. It reduces an ammoniacal solution of silver salts, is converted into a resin by alkalies, and polymerizes with great readiness.

The presence of the double bond is shown by the fact that acrolein unites with two atoms of bromine and forms a compound of the structure $CH_2Br.CHBr.CHO$.

The presence of the double bond modifies to some extent the reactions of the aldehyde group in acrolein; it does not unite with ammonia to form an addition-product similar to that formed by acetaldehyde and most other saturated aldehydes. The union of acrolein with ammonia takes place according to the equation, —

$$2C_3H_4O + NH_3 = C_6H_9NO + H_2O.$$

Acrolein-ammonia is an amorphous basic substance which resembles glue in physical properties.

The presence of the aldehyde group in acrolein modifies the reactions of the doubly-linked carbon atoms. Acrolein unites with two molecules of sodium bisulphite. As but one molecule is removed when the addition-product is heated with acids, it is probable that the other is added to the compound as the result of the breaking of the double bond. Unsaturated hydrocarbons do not unite with acid sulphites.

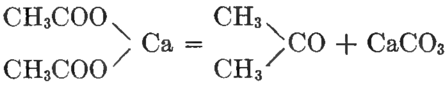
154. Geranial, also called citral, is an example of an aldehyde which contains two double bonds. It is an important constituent of various essential oils, among which are those derived from lemons, geraniums, roses, and orange-rind. It is a liquid, which possesses an agreeable odor and boils at 110°–112° under a pressure of 12 mm. An interpretation of the methods used in its synthesis and of its reactions leads to the conclusion that its structure is represented by the formula, —

$$(CH_3)_2C:CH.CH_2.CH_2.C(CH_3):CH.CHO$$

Ketones

155. Acetone, $(CH_3)_2CO$, is the first member of the series of ketones which contain saturated alkyl groups. It is a colorless liquid which has a specific gravity of 0.792 at 20° and boils at 56.5°; it has a characteristic odor and is miscible with water. Acetone occurs in small quantities in normal urine, but the amount is greatly increased in severe cases of diabetes. It is a good solvent for resins, gums, and many organic compounds, and is used in varnish removers. It is also used in the preparation of chloroform, iodoform, sulphonal, and other substances used in pharmacy.

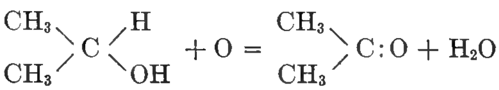
Acetone is obtained as the result of the distillation of wood (**47**). It is usually prepared by the destructive distillation of calcium acetate: —



$$\begin{matrix}CH_3COO\\CH_3COO\end{matrix}\!\!>Ca = \begin{matrix}CH_3\\CH_3\end{matrix}\!\!>CO + CaCO_3$$

The acetone prepared in this way contains impurities from which it may be freed by treatment with acid sodium sulphite. Pure acetone is liberated from the crystalline addition-product formed, by heating the latter with a solution of sodium carbonate. Water is removed by fractional distillation, and the acetone is finally dried over calcium chloride and distilled.

The formation of acetone as the result of the oxidation of isopropyl alcohol is of interest, as it throws light on the relation which exists between the structures of these compounds: —

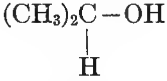


$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>C<\!\!\begin{matrix}H\\OH\end{matrix} + O = \begin{matrix}CH_3\\CH_3\end{matrix}\!\!>C:O + H_2O$$

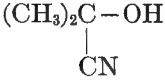
The ketone is also formed when isopropyl alcohol is heated in the presence of finely divided copper. A decomposition takes place analogous to that by which primary alcohols yield aldehydes: —

$$(CH_3)_2CHOH = (CH_3)_2CO + H_2$$

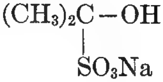
Reactions of Acetone. — Many of the reactions of acetone are determined by the presence in it of a carbonyl group. It forms addition-products with hydrogen, hydrocyanic acid, and sodium hydrogen sulphite, the structures of which are represented by the formulas, —



$$\begin{array}{l}(CH_3)_2C-OH\\ \qquad\ \ |\\ \qquad\ \ H\end{array}$$

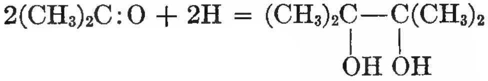


$$\begin{array}{l}(CH_3)_2C-OH\\ \qquad\ \ |\\ \qquad\ \ CN\end{array}$$



$$\begin{array}{l}(CH_3)_2C-OH\\ \qquad\ \ |\\ \qquad\ \ SO_3Na\end{array}$$

It does not form, however, an addition-product with ammonia similar to that derived from aldehyde, but complex condensation products. When reduced by nascent hydrogen generated by the action of sodium amalgam on water, addition takes place as indicated above, and isopropyl alcohol is formed, but at the same time a diatomic alcohol, which contains six carbon atoms, is produced in appreciable quantities. This substance, called *pinacone*, is the first member of a series of such alcohols which are formed by the reduction of ketones. The equation for the reaction in the case of acetone is,



$$2(CH_3)_2C:O + 2H = \begin{array}{c}(CH_3)_2C—C(CH_3)_2\\ \quad\ |\qquad |\\ \quad OH\ \ OH\end{array}$$

Ketones resemble aldehydes in that they form oximes and hydrazones, which are useful in the identification of members of this class of compounds. The structure of the compounds derived from acetone and hydroxylamine and phenylhydrazine, are, respectively, —

$$(CH_3)_2C{=}NOH \qquad (CH_3)_2C{=}N.NHC_6H_5$$

156. Acetone does not polymerize. It does, however, undergo condensation with loss of water, when treated with certain dehydrating reagents. When it is saturated with dry hydrogen chloride and allowed to stand for some time, a mixture of two unsaturated ketones, called *mesityl oxide* and *phorone*, is formed. A study of the reactions of these substances leads to the constitutions expressed by the following formulas: —

$(CH_3)_2C=CH.CO.CH_3$	$(CH_3)_2C=CH.CO.CH=C(CH_3)_2$
mesityl oxide	phorone

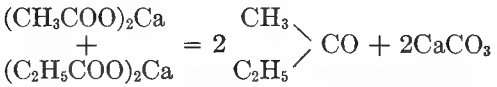
The condensation in these cases resembles that in which crotonic aldehyde is formed from acetaldehyde. In the three cases the oxygen of a carbonyl group unites with two hydrogen atoms of a methyl group, and water and an unsaturated compound are formed.

Acetone reacts readily with chlorine and bromine. The substitution-products formed are characterized by their exceedingly irritating action on the eyes.

When acetone is treated with phosphorus pentachloride, the oxygen atom is replaced by two halogen atoms. An unsaturated halogen compound is also formed as the result of the elimination of hydrogen chloride: —

$$(CH_3)_2CO + PCl_5 = (CH_3)_2CCl_2 + POCl_3$$
$$CH_3CCl_2CH_3 = CH_2{:}CCl.CH_3$$

157. Homologues of Acetone. — These compounds may be prepared by the distillation of the calcium salts of the fatty acids. If a mixture of the salts of two acids is used, a ketone is obtained which contains the two radicals present in the acids used. Thus, calcium acetate and calcium propionate yield methyl-ethyl ketone: —



$$\begin{matrix}(CH_3COO)_2Ca\\+\\(C_2H_5COO)_2Ca\end{matrix} = 2\;\begin{matrix}CH_3\diagdown\\ \\C_2H_5\diagup\end{matrix}CO + 2CaCO_3$$

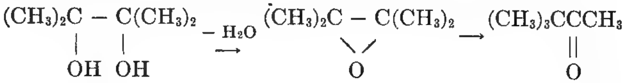
Acetone and diethyl ketone are obtained at the same time as the result of the decomposition of the acetate and propionate.

Ketones can be prepared by the replacement of the halogen atom of an acyl halide (e.g. CH_3COCl) by an alkyl group. This replacement can be effected as the result of the action of certain organic compounds which contain metals. The zinc alkyls or magnesium alkyl halides are generally used. Methyl ethyl ketone can be prepared in this way from acetyl chloride and magnesium ethyl iodide: —

$$2CH_3COCl + 2C_2H_5MgI = 2CH_3COC_2H_5 + MgCl_2 + MgI_2$$

An intermediate product is formed as the result of the addition of the acid chloride and magnesium alkyl halide, the addition taking place in a way similar to that which has been explained (**144**). This synthetic method is an important one, as it serves to replace a halogen atom in an acyl halide by an alkyl group.

Ketones which contain a tertiary alkyl group are formed as the result of the elimination of water from pinacones. When pinacone is heated with an aqueous solution of an acid, it loses water and forms a ketone, named *pinacoline,* which is the first member of a series of substances known as pinacolines. In the transformation a molecular rearrangement evidently takes place. The probable course of the reaction is expressed by the formulas, —



$$\begin{matrix}(CH_3)_2C - C(CH_3)_2\\ |\qquad\quad |\\ OH\quad OH\end{matrix} \xrightarrow{-H_2O} \begin{matrix}(CH_3)_2C - C(CH_3)_2\\ \diagdown\;\diagup\\ O\end{matrix} \longrightarrow \begin{matrix}(CH_3)_3CCCH_3\\ \|\\ O\end{matrix}$$

pinacone pinacoline

The conclusion that pinacoline has the constitution assigned to it here, has been reached as the result of the study of the reactions of the compound. Its formation as the result of the elimination of water from pinacone would lead to the view that it is an ether, and has the structure represented by the middle formula in the series above. Pinacoline, however, shows the reactions which are characteristic of ketones. The intermediate product in the transformation of a pinacone to a pinacoline has been isolated in certain cases.

The reactions of the ketones are similar to those of acetone. Most ketones, however, which do not contain the group CH_3CO do not unite with sodium hydrogen sulphite.

The products formed as the result of the oxidation of ketones often serve as a guide in the determination of their structure. The compounds break at the carbonyl group and acids are formed. Thus, ethyl-amyl ketone breaks at the points indicated in the following formulas: —

$$CH_3CH_2|COC_5H_{11} \qquad CH_3CH_2CO|C_5H_{11}$$

If the ethyl group is eliminated, acetic acid, CH_3COOH, and caproic acid, $C_5H_{11}COOH$, are obtained. If decomposition takes place according to the second formula, propionic acid, $CH_3CH_2.COOH$, and valeric acid, C_4H_9COOH, result. The oxidation of most ketones takes place, in large part, in such a way that the smaller radical remains in combination with the carbonyl group. The position of the carbonyl group in ketones can, therefore, be frequently determined by oxidation. The structure of the ketone which is the chief constituent of the *oil of rue* has been determined in this way. As it yields acetic acid and pelargonic acid, $C_8H_{17}COOH$, on oxidation, it is methyl nonyl ketone, $CH_3COC_9H_{19}$.

The physical properties of the higher ketones resemble closely those of the aldehydes. Ketones, however, have, in general, a not unpleasant odor.

158. Reactions of Ketones of Analytical Significance. — In the identification of a substance as a ketone, an oxime or a phenylhydrazone is usually prepared from it. In the case of ketones which contain the $CH_3CO\cdot$ group, crystalline addition-products with sodium hydrogen sulphite may be formed. As these reactions are shown by aldehydes, the substance must be tested to determine the presence or absence of the CHO group. Ketones do not reduce Fehling's solution or an ammoniacal solution of silver nitrate,[1] and produce a color with Schiff's reagent only after standing some time.

PROBLEMS

1. Write equations for the reactions by which aldehydes and ketones may be prepared.

2. Summarize the typical reactions of aldehydes and ketones.

3. How can aldehydes be distinguished from ketones?

4. Write equations for the reactions by which acetic aldehyde may be converted into (*a*) ethyl alcohol, (*b*) *sec*-butyl alcohol, and (*c*) methyl-ethyl ketone.

5. Starting with acetone show by what reactions the following may be prepared: (*a*) $CH_3.CCl=CH_2$, (*b*) $(CH_3)_2(C_2H_5)COH$, (*c*) $(CH_3)_2COH.COOH$, (*d*) $CH_3.CO.CCl_3$, (*e*) $CH_2Cl.CHOH.CH_3$.

6. By what reactions can (*a*) C_2H_5OH be converted into CH_3CHCl_2, (*b*) $(CH_3)_2CHOH$ into $(CH_3)_2CCl_2$, (*c*) CH_3CHO into CCl_3COOH?

7. By what chemical tests could you distinguish (*a*) acrylic aldehyde from acetic aldehyde, (*b*) acetone from ethyl acetate, (*c*) pinacoline from *ter*-butyl alcohol?

8. How could you separate by chemical means (*a*) geranial from a hydrocarbon, (*b*) acetone from ether, (*c*) diethyl ketone from acetone?

9. Write equations for reactions by which crotonic aldehyde, $CH_3CH=CH.CHO$, may be prepared from acetaldehyde through the formation of aldol.

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[1] Exceptions to this statement are ketones which contain the group —CHOH.CO— (**289**).

CHAPTER XI

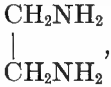
AMINES AND AMIDES

159. In the discussion of certain classes of organic compounds it was convenient to consider them as derived from water by the replacement of one or both hydrogen atoms by radicals. The relation between alcohols, acids, ethers, anhydrides, and esters was indicated in this way. It was shown that the properties of the compounds so derived, varied with the positive or negative nature of the radical introduced. Certain important classes of compounds which contain nitrogen may be considered in the same way as substitution-products of ammonia. It will be seen in the case of these compounds, also, that the nature of the group which replaces the hydrogen determines the characteristic chemical properties of the resulting compounds. When a positive group is the substituent, the substances are called amines. As ammonia contains three hydrogen atoms that may be replaced, three classes of amines are possible, and three are known. Thus, the compounds which have the composition represented by the formulas $(CH_3)NH_2$, $(CH_3)_2NH$, and $(CH_3)_3N$ are methylamine, dimethylamine, and trimethylamine, respectively. They are representatives of the classes known as primary, secondary, and tertiary amines. Substitution-products of ammonium hydroxide in which four hydrogen atoms are replaced by alkyl radicals exist and form an interesting class of compounds. Ammonium hydroxide has never been isolated, as, when an attempt is made to obtain it, it undergoes decomposition spontaneously with the formation of ammonia and water. It probably exists, however, in aqueous solution. When the four hydrogen atoms in the ammonium radical are replaced by alkyl groups an analogous decomposition does not take place; stable compounds result, of which tetramethyl-ammonium hydroxide, $(CH_3)_4N.OH$, is an example. Compounds of this type are known as quarternary ammonium bases.

The amines resemble ammonia in chemical properties. Thus they unite with acids and form well characterized salts; methylamine, for example, combines with hydrochloric acid and forms a salt which is called methylamine hydrochloride: —

$$CH_3NH_2 + HCl = CH_3NH_2.HCl$$

The salt is sometimes called methylammonium chloride, and its formula written CH_3NH_3Cl to bring out its relation to ammonium chloride. The replacement of hydrogen by positive alkyl groups yields compounds in which the positive nature of the molecule is more highly developed than in ammonia. As a consequence, when the amines are dissolved in water, bases are obtained which are stronger than ammonium hydroxide. The accumulation of positive radicals in the quarternary ammonium bases results in the production of marked basic properties in these compounds. Tetramethyl-ammonium hydroxide shows about as strong basic properties as potassium hydroxide.

Amines which are derived from bivalent radicals are also known. Ethylene diamine,  $\begin{array}{l}CH_2NH_2\\ |\\ CH_2NH_2\end{array}$, is an example of this type. The diamines resemble closely in chemical properties the simple amines.

160. The compounds formed by the replacement of hydrogen atoms by acyl radicals are called amides. Acetamide, $CH_3CO.NH_2$, diacetamide, $(CH_3CO)_2NH$, and triacetamide $(CH_3CO)_3N$, are examples of the three classes of compounds which exist. Of the amides only those which contain one acyl group will be considered here.

The replacement of a hydrogen atom in the weakly positive ammonia molecule by the negative radical has a marked effect on the chemical properties of the resulting compound. The amides are neutral to indicators and form salts only with the most active inorganic acids. In the presence of a large excess of concentrated hydrochloric acid acetamide forms the compound $CH_3CONH_2.HCl$, and when it is dissolved in a mixture of alcohol and ether and treated with dry hydrogen chloride, an addition-product of the formula $(CH_3CONH_2)_2.HCl$ is formed. These substances are hydrolyzed by water, and the amide is set free. Diacetamide, which contains two acid radicals, does not form addition-products with acids; the basic property of the ammonia molecule is completely destroyed as the result of the replacement of two hydrogen atoms by negative radicals.

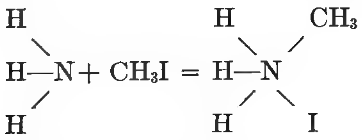
The amides which contain one acyl group may be considered as substitution-products of acids formed by the replacement of the hydroxyl by the NH_2 group. As this group occurs in many organic compounds, it has been given the name *amido*. When it is in combination with a positive radical and shows, therefore, basic properties it is called the *amino* group to emphasize the relation of the compound in which it is present to the amines.

AMINES

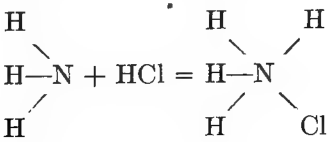
161. Methylamine, CH_3NH_2, is a gas which can be condensed by cooling to a liquid which boils at $-6°$. It is very soluble in water; 1150 volumes of the gas are absorbed by one volume of water at 12.5°. The odor of methylamine resembles closely that of ammonia.

Methylamine is produced in small quantities in the decomposition of nitrogenous organic matter, and is one of the products of the distillation of animal matter and of wood. It occurs in herring brine along with dimethylamine and trimethylamine, and in *Mercurialis perennis.*

It may be prepared by heating methyl iodide with a strong aqueous solution of ammonia in a sealed vessel under pressure. In the reaction which takes place the valence of nitrogen increases from three to five: —



The reaction is analogous to the formation of an ammonium salt from ammonia: —



Addition takes place, however, with the alkyl halide more slowly than with a hydrogen halide, and, as a consequence, heating the substances at a high temperature for some time is required to effect the formation of the substituted ammonium salt.

The amine is obtained from the methylammonium iodide formed, by treatment with an aqueous solution of a base. The reaction is analogous to that by which ammonia is liberated from its salt, and takes place instantaneously: —

$$CH_3NH_3I + KOH = CH_3NH_2 + KI + H_2O.$$

162. As substitution-products of ammonium iodide which contain two, three, and four alkyl groups are obtained along with methylammonium iodide by the action of ammonia on methyl iodide — a fact explained below — the compound is most readily prepared in the pure condition from acetamide by what is known as *Hofmann's reaction.* When an amide is treated with bromine and an aqueous solution of sodium hydroxide, the first reaction which takes place consists in the replacement of one of the hydrogen atoms in the amido group by bromine. The equation for the reaction in the case of acetamide is, —

$$CH_3CONH_2 + Br_2 + KOH = CH_3CONHBr + KBr + H_2O$$

The exchange of hydrogen for bromine in this case is accomplished in a way which is identical with that used to bring about a similar exchange in the case of ammonia itself. The student will recall the fact that when ammonia is treated with a solution of iodine in an alkali, iodide of nitrogen is obtained. The reaction is a general one in organic chemistry; both amines and amides yield halogen substitution-products in which the halogen atom is in combination with nitrogen, when treated with solutions of hypochlorites, hypobromites, or hypoiodites.

When acetbromamide is heated with an excess of alkali, a second reaction takes place as the result of which methylamine is formed: —

$$CH_3CONHBr + 3KOH = CH_3NH_2 + K_2CO_3 + KBr + H_2O$$

Hofmann's reaction is a valuable method of preparing primary amines. As carbon is removed in the form of a carbonate from an amide, it serves as a means of passing from one member of an homologous series to the next which contains one less carbon atom. As acetamide is obtained from acetic acid, which is formed as the result of the oxidation of ethyl alcohol, and as methylamine, as will be shown later, is readily converted into methyl alcohol, it is possible through the application of this reaction to pass from ethyl alcohol to methyl alcohol, or in general from any alcohol to the one in the series with it which contains one less carbon atom. As the other classes of compounds may be prepared from alcohols, it is, thus, possible to "build down" in any homologous series. The steps in passing from ethyl alcohol to methyl alcohol are indicated by the following formulas: —

$$C_2H_5OH \rightarrow CH_3COOH \rightarrow CH_3CONH_2 \rightarrow CH_3CONHBr \rightarrow CH_3NH_2 \rightarrow CH_3OH$$

163. The reactions of methylamine confirm in a striking manner the structure which has been assigned to it. It resembles ammonia markedly in chemical properties. The gas fumes when brought into contact with hydrochloric acid as the result of the formation of a salt — methylammonium chloride: —

$$CH_3NH_2 + HCl = CH_3NH_3Cl$$

It forms with acids salts which crystallize well and unite with metallic salts to form double salts which resemble those containing ammonium. The solution of the gas in water acts as a base and can be titrated with acids. It precipitates the hydroxides of the heavy metals, some of which are soluble in excess of the solution of the amine.

The salts of methylamine, like those of amines in general, are decomposed by bases: —

$$CH_3NH_3Cl + KOH = CH_3NH_2 + KCl + H_2O$$

When methylamine is treated with nitrous acid, a reaction takes place which is analogous to that between ammonia and the acid. In the cold a nitrite is formed, but when gently heated decomposition takes place and nitrogen is set free. The reactions in the case of ammonia and methylamine are represented by the equations, —

$$NH_3 + HNO_2 = N_2 + H_2O + HOH$$
$$CH_3NH_2 + HNO_2 = N_2 + H_2O + CH_3OH$$

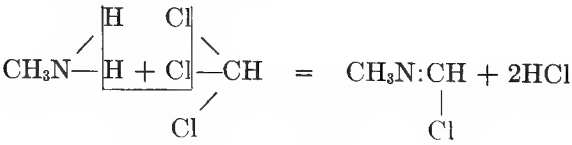
Two molecules of water are formed from the ammonium salt. In the case of the amine, as one hydrogen is replaced by a methyl radical, a molecule of methyl alcohol is produced. This reaction is one of importance as it is characteristic of substances which contain the NH_2 group. Nitrogen is not set free as the result of the action of nitrous acid on secondary or tertiary amines.

Methylamine, like ammonia, reacts readily with acid chlorides. The equations for the reactions in the case of acetyl chloride are, —

$$CH_3CO.Cl + NH_3 = CH_3CO.NH_2 + HCl$$
$$CH_3CO.Cl + CH_3NH_2 = CH_3CO.NHCH_3 + HCl$$

Amides are conveniently prepared by the first reaction; the second yields substitution-products of ammonia which contain one positive and one negative radical.

164. Certain compounds which contain halogen, other than acid chlorides, react with amines and form condensation-products as the result of the elimination of a hydrogen halide. The reaction of methylamine with chloroform, $CHCl_3$, in the presence of an alkali is an example of a reaction of this type. In this case, both hydrogen atoms joined to nitrogen unite with chlorine to form hydrochloric acid, and an intermediate compound is probably formed, which is unstable and loses another molecule of the acid. The steps in the reactions may be represented by the following equations: —



$$CH_3N\begin{array}{l}\diagup\boxed{H\quad Cl}\diagdown\\ —\boxed{H + Cl}—CH\\ \qquad\qquad\ \diagup\\ \qquad\qquad Cl\end{array} = CH_3N{:}\underset{\displaystyle Cl}{\underset{|}{CH}} + 2HCl$$

$$CH_3N{:}CHCl = CH_3N{:}C + HCl$$

The reaction takes place only in the presence of an alkali, which brings about the removal of the acid. The product of the reaction is methyl isocyanide, which is isomeric with methyl cyanide, the structure of which is represented by the formula $CH_3C{\equiv}N$. It will be recalled that the cyanides or nitriles can be converted into acids by hydrolysis; for example, methyl cyanide, $CH_3.CN$, yields acetic acid, $CH_3.COOH$. This fact is evidence that in the cyanides the carbon atoms are in direct combination. In the isomeric compounds — the isocyanides or isonitriles — the carbon atoms are linked through nitrogen. The isocyanides possess disagreeable odors, which are readily recognized. This fact is taken advantage of in testing for primary amines. When such an amine is warmed with chloroform and an alcoholic solution of potassium hydroxide, the characteristic odor is produced. As the reaction involves the elimination from the amine of two hydrogen atoms joined to nitrogen, it is evident that only the compounds which contain the NH_2 group take part in this reaction, which serves, therefore, as a test for a primary amine. The isocyanides were formerly called carbylamines. The reaction by which they are produced from primary amines is known as the *carbylamine reaction.*

165. Dimethylamine, $(CH_3)_2NH$, is a representative of the class of secondary amines. It resembles closely methylamine in physical and chemical properties. It is a gas, with a strong, fishy odor, and can be condensed to a liquid which boils at 7.2°. It is formed when methyl iodide is heated with ammonia. Methylamine is first formed and then converted into dimethylamine. The first reaction consists in the addition of the halide and ammonia: —

$$CH_3I + NH_3 = CH_3NH_3I$$

The methylammonium iodide then probably interacts with ammonia according to the equation, —

$$CH_3NH_3I + NH_3 = NH_4I + CH_3NH_2$$

The methylamine produced unites with methyl iodide and forms dimethylammonium iodide: —

$$CH_3NH_2 + CH_3I = (CH_3)_2NH_2I$$

From this salt dimethylamine is obtained by decomposition with an alkali, —

$$(CH_3)_2NH_2I + KOH = (CH_3)_2NH + KI + H_2O$$

When methyl iodide and ammonia are heated together, the reaction does not stop with the formation of the salt of the secondary amine. The amine is liberated, and by the addition of another molecule of the iodide is converted into the salt of trimethylamine, $(CH_3)_3NHI$. Still another step in the reaction takes place. The tertiary amine is set free and a quarternary ammonium salt is formed as the result of the addition of methyl iodide: —

$$(CH_3)_3N + CH_3I = (CH_3)_4N.I$$

With the formation of this salt reaction ceases. The reaction between ammonia and an alkyl halide thus yields a mixture of the salts of the three classes of amines together with the salt of the quarternary ammonium base. The extent to which any one of the possible reactions predominates over the others, is determined by the nature of the radical of the alkyl halide, and by the conditions under which the reaction takes place.

Dimethylamine is prepared conveniently in the laboratory from dimethylaniline (**422**). It is formed, along with trimethylamine, when the residue obtained in the production of sugar from beets is subjected to destructive distillation. This is the commercial source of these two amines.

The reaction which takes place between dimethylamine and nitrous acid is of importance, as it is an example of a general reaction used to distinguish secondary amines from the other classes of amines. Nitrous acid reacts with dimethylamine and forms a substance which belongs to the class known as nitroso compounds: —

$$(CH_3)_2NH + HO.N{:}O = (CH_3)_2N.N{:}O + H_2O$$

The reaction brings about the replacement of the hydrogen in the NH group by the nitroso group $(N=O)$. Nitroso-dimethylamine, is formed as a light yellow, insoluble liquid when sodium nitrite is added to an acidified aqueous solution of a salt of dimethylamine.

Acid chlorides react with secondary amines: —

$$(CH_3)_2NH + CH_3CO.Cl = CH_3CO.N(CH_3)_2 + HCl$$

The reaction takes place in most cases on simply mixing the reacting substances. No hydrochloric acid is evolved as that formed unites with a part of the amine to form a salt: —

$$(CH_3)_2NH + HCl = (CH_3)_2NH_2Cl$$

166. Trimethylamine, $(CH_3)_3N$, is a gas with a penetrating fishy odor, which may be condensed to a liquid that boils at 3.2°–3.8°. It is prepared commercially from the residues of the beet-sugar industry, and from methyl chloride and ammonia. Trimethylamine, like other amines, forms salts with acids, and unites with alkyl halides: —

$$(CH_3)_3N + HCl = (CH_3)_3NHCl$$
$$(CH_3)_3N + CH_3I = (CH_3)_4NI$$

The amine is liberated from its salts when they are treated with a base: —

$$(CH_3)_3NHCl + KOH = (CH_3)_3N + KCl + H_2O$$

167. Tetramethylammonium Hydroxide, $(CH_3)_4N.OH$. — This substance contains the largest number of methyl groups which can be held in combination with nitrogen. Attempts to prepare a substance of the structure $(CH_3)_5N$ and similar compounds in which five positive groups are linked to nitrogen, have failed. The nitrogen atom appears to be able to exhibit a valence of five only when at least one of the atoms or groups in combination with it is of a negative nature.

Tetramethylammonium hydroxide is a colorless hygroscopic solid, which is very soluble in water and decomposes when strongly heated. It is prepared from the tetramethylammonium salt which is formed from trimethylamine and methyl iodide. The base can not be prepared by heating the salts with alkalies, as in the case of the preparation of the amines, as it is not volatile without decomposition. It is formed when tetramethylammonium iodide is shaken with silver oxide suspended in water: —

$$(CH_3)_4NI + AgOH = (CH_3)_4N.OH + AgI$$

The double decomposition takes place in this case as the result of the insolubility of silver iodide. When tetramethylammonium chloride is treated with potassium hydroxide, and alcohol is used as the solvent, the base is formed as the result of the fact that potassium chloride is insoluble in alcohol: —

$$(CH_3)_4NCl + KOH = (CH_3)_4N.OH + KCl$$

The salts of the amines and quarternary ammonium bases resemble inorganic salts in that they are ionized, and, consequently, take part in reactions of double decomposition.

168. Homologues of the Methylamines. — Many amines and quarternary ammonium bases are known. The effect of structure and content of carbon on the boiling-points of amines is shown in the following table, which includes the lower members of the series only: —

BOILING-POINTS OF AMINES

Alkyl Radical	Primary	Secondary	Tertiary
Methyl	−6°	7°	3.5°
Ethyl	19°	56°	90°
n-Propyl	49°	98°	156°
n-Butyl	76°	160°	215°
n-Octyl	180°	297°	366°

The amines with a small number of carbon atoms are inflammable gases, which are very soluble in water, and possess a characteristic ammoniacal, fishy odor. The higher members are odorless, and insoluble in water. The specific gravities of the amines are less than one.

The amines may be prepared by the methods mentioned in the consideration of the methylamines. They are formed by other reactions than those described. Primary amines result from the reduction of nitro compounds, cyanides, oximes, and hydrazones: —

$$CH_3NO_2 + 4H = CH_3NH_2 + 2H_2O,$$
$$CH_3CN + 4H = CH_3CH_2NH_2,$$
$$(CH_3)_2C{:}NOH + 4H = (CH_3)_2CHNH_2 + H_2O,$$
$$(CH_3)_2C{:}N.NH_2 + 3H = (CH_3)_2CHNH_2 + NH_3.$$

Primary amines are also formed when the esters of isocyanic acid are distilled with an alkali, the reaction being analogous to the decomposition of isocyanic acid: —

$$HNCO + 2KOH = K_2CO_3 + NH_3,$$
$$C_2H_5NCO + 2KOH = K_2CO_3 + C_2H_5NH_2.$$

The reaction is of interest as the first amine discovered was obtained in this way from ethyl isocyanate by Wurtz in 1848.

Amines which contain two or more different radicals can be prepared by the addition of alkyl halides to amines: —

$$CH_3NH_2 + C_2H_5I = CH_3NH_2C_2H_5I,$$
$$CH_3NH_2C_2H_5I + KOH = CH_3.C_2H_5.NH + KI + H_2O.$$

169. Reactions of Amines. — The more important chemical properties of the amines have been illustrated in the consideration of the methylamines. They form salts with acids, such as nitric, sulphuric, and carbonic acids. The salts resemble inorganic salts in that they are ionized in solution. The presence of chlorine in dimethylamine hydrochloride, can be shown, for example, by the tests used in inorganic qualitative analysis. The salts of hydrochloric, hydrobromic, and hydriodic acids are, in general, soluble in alcohol and by the use of this solvent the substituted ammonium chlorides may be separated from ammonium chloride. The double chlorides which contain the amines and platinum are difficultly soluble in alcohol, and are of service in separating amines from other substances. The platinochloride which contains dimethylamine hydrochloride has the formula $PtCl_4.2(C_2H_5)_2NH_2Cl$. A number of substitution-products of the amines are formed as the result of the decomposition of animal matter. The amines are frequently isolated by converting them into double salts, from which the former may be obtained by the action of a caustic alkali.

Sodium hypochlorite brings about the replacement by chlorine of the hydrogen joined to nitrogen. Thus, with this reagent dipropylamine yields chlordipropylamine, $(C_3H_7)_2NCl$.

170. Identification of Amines. — When the qualitative analysis of a substance shows that it contains nitrogen the test for amines should be applied. If the substance is soluble in water and crystalline it may be a salt of an amine. This may be determined by adding a solution of sodium hydroxide, when, if the compound is a salt, the amine will be set free. If an amine is liberated, the acid radical of the salt should be determined by the application of the ordinary tests for chlorides, sulphates, etc. The amine may be identified by the determination of its physical properties and those of a salt. Salts of most amines with hydrochloric, hydrobromic, and hydriodic acid melt without decomposition at temperatures that may be easily determined in the usual way. The determination of the melting-points of the salts of amines which are gases at ordinary temperatures, is the most convenient way to effect their identification. If the substance is not a salt it may be a free amine. In this case it will dissolve in acids and a salt will be formed. Tripropylamine, for example, is an oil which is insoluble in water. It dissolves in dilute hydrochloric acid and is precipitated from the solution on the addition of an alkali. In the identification of certain amines it is often convenient to prepare and determine the melting-point of their acetyl derivatives.

It is often advisable to determine to which class an amine belongs. There are many ways of distinguishing between and separating primary, secondary, and tertiary amines. Only a few will be mentioned here. Acetyl chloride reacts at ordinary temperatures with primary and secondary amines. Heat is evolved, and in most cases solids are formed from liquid amines. Inactivity with this reagent indicates that the substance, previously shown to be an amine, is a tertiary amine. If an acetyl derivative is formed, the carbylamine test (**163**) is applied. Some of the original substance is warmed with chloroform and an alcoholic solution of potassium hydroxide. The production of the characteristic, disagreeable odor is evidence that the substance is a primary amine.

The three classes of amines may also be distinguished from one another by means of nitrous acid. An acidified solution of a salt of the amine is gently warmed with sodium nitrite. Nitrogen is evolved in the case of primary amines and an alcohol is formed. Insoluble nitroso-compounds are formed from secondary amines. Most tertiary amines either do not react with nitrous acid or are oxidized by it. Care must be exercised in making this test. If a tertiary amine is present, the solution evolves oxides of nitrogen when heated, as the result of the decomposition of the nitrous acid produced from the sodium nitrite. The formation of a gas is not, therefore, proof that a primary amine is present. The gas evolved must be shown to be nitrogen, which can be separated from its oxides by passing the gases through a saturated solution of ferrous sulphate. The latter dissolves the oxides of nitrogen.

A convenient method of identifying the three classes of amines is that devised by Hinsburg (**395**).

UNSATURATED AMINES AND RELATED COMPOUNDS

171. Vinylamine, $CH_2{=}CH.NH_2$, is an example of an amine which contains an unsaturated radical. It is made by an application of the general methods used in preparing unsaturated compounds. When bromethylamine is heated with a solution of potassium hydroxide, hydrobromic acid is eliminated from the saturated compound: —

$$BrCH_2CH_2.NH_2 + KOH = CH_2{:}CH.NH_2 + KBr + H_2O$$

The amine is an insoluble oil which boils at 55°–56°. It unites readily with halogen acids, and forms substitution-products of ethylamine. When treated with sulphurous acid, addition takes place at the double bond: —

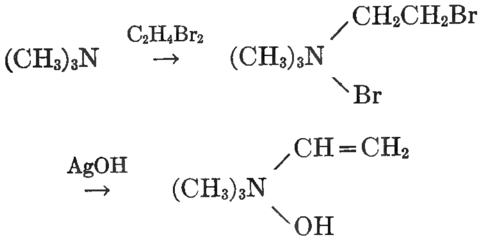
$$CH_2{:}CH.NH_2 + H_2SO_3 = CH_2(SO_3H)CH_2NH_2$$

The substance formed is *taurine,* which is found in the bile in combination with cholic acid.

172. Neurine, $(CH_3)_3N(CH{=}CH_2).OH$, is a quarternary ammonium base which contains three methyl and one vinyl radicals. It is formed during the putrefaction of meat. It is very poisonous, and belongs to the class of substances known as *ptomaines.* This name has been given to the basic compounds formed during the decay of animal or vegetable matter, which is brought about by the action of bacteria. Many ptomaines are poisonous, and their occurrence in stale meat and fish has frequently caused death.

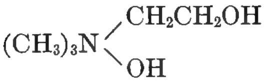
Neurine is a strong base and forms well characterized salts.

It can be synthesized by the method indicated by the following formulas: —

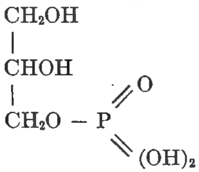


$$(CH_3)_3N \xrightarrow{C_2H_4Br_2} (CH_3)_3N\begin{matrix}\diagup CH_2CH_2Br\\ \diagdown Br\end{matrix} \xrightarrow{AgOH} (CH_3)_3N\begin{matrix}\diagup CH{=}CH_2\\ \diagdown OH\end{matrix}$$

In the decomposition of animal and vegetable matter neurine is probably formed as the result of the elimination of water from choline.

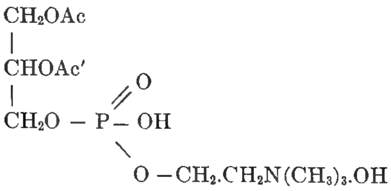
173. Choline,  $(CH_3)_3N\begin{matrix}\diagup CH_2CH_2OH\\ \diagdown OH\end{matrix}$, is a constituent of complicated compounds, called lecithins, which occur in bile, the brain, nerve tissue, the envelope of the red blood corpuscle, yolk of eggs, many seeds, and other animal and vegetable substances.

174. Lecithins are derived from glycerol by the replacement of the hydrogen atoms of the hydroxyl groups by certain acid radicals, one of which is the radical of phosphoric acid. When a lecithin is treated with barium hydroxide partial saponification takes place. Choline and palmitic, stearic, or oleic acid are obtained, together with glycerophosphoric acid which has the constitution: —



$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2O - P\begin{matrix}\diagup\!\!\diagup O\\ \diagdown\!\!\diagdown (OH)_2\end{matrix}\end{array}$$

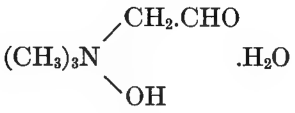
The general formula of a lecithin is, —



$$\begin{array}{l} CH_2OAc \\ | \\ CHOAc' \\ | \\ CH_2O - P\begin{matrix}\diagup\!\!\diagup O\\ - OH\\ \diagdown O-CH_2.CH_2N(CH_3)_3.OH\end{matrix}\end{array}$$

Ac and Ac′ designate the acid radicals of palmitic, stearic, or oleic acids. The radicals in a lecithin may be the same or different. The choline present in the molecule is united to the phosphorus atom through oxygen joined to carbon. It is, therefore, present in the form of an ester. The hydroxyl group of choline which is joined to nitrogen is free. A lecithin has, consequently, basic properties and forms salts with acid. It also forms salts with bases as the result of the replacement of the hydrogen of the hydroxyl group joined to phosphorus.

175. Muscarine is a very poisonous substance which occurs in toad-stools (*Agaricus muscarius*) and certain other plants. It belongs to the class of compounds known as *alkaloids*, which are basic substances that occur in plants. The chemical properties of muscarine indicate that it is closely related in structure to choline. The latter is a primary alcohol; muscarine is the corresponding aldehyde. Its constitution is represented by the formula, —



$$(CH_3)_3N\begin{matrix}\diagup CH_2.CHO \\ \diagdown OH\end{matrix}.H_2O$$

DIAMINES

176. Ethylene Diamine, $NH_2CH_2CH_2NH_2$, is the lowest member of the series of diamines. It is a liquid which boils at 116.5°, and has a weak ammoniacal odor. It may be prepared from ethylene bromide and ammonia. The reactions of ethylene diamine are analogous to those of other primary amines. It differs from these, however, in that it forms a stable addition-product with water which may be distilled without decomposition. The substance is, in all probability, a derivative of ammonium hydroxide with the structure, —

$$NH_2CH_2CH_2NH_3.OH$$

Tetramethylene Diamine, $NH_2(CH_2)_4NH_2$, usually called *putrescine*, is formed in the decay of animal matter. It melts at 27°–28°, and boils at 158°.

Cadaverine, $NH_2(CH_2)_5NH_2$, is a ptomaine, which is formed in the putrefaction of the human cadaver. It is a liquid, which boils at 178°–179°, and is not poisonous. Its structure is indicated by its synthesis from trimethylene cyanide: —

$$NC.CH_2.CH_2.CH_2.CN + 8H = H_2N.CH_2.CH_2.CH_2.CH_2.CH_2.NH_2$$

AMIDES

177. The primary amides of the fatty acids, with the exception of formamide, which is a liquid, are colorless, crystalline solids. The lower members of the series are very soluble in water, and distill without decomposition at atmospheric pressure. As ordinarily prepared, they have a disagreeable odor, which, in certain cases, has been shown to be due to impurities. The boiling-points of the amides increase in most cases with the increase in the number of carbon atoms, but the differences between the boiling-points of adjacent members is not so great as in other homologous series. The relative effect on the boiling-point of the replacement of the hydroxyl groups in alcohol and acids by the amido group is very marked. While the boiling-point of an amine is lower than that of the alcohol which contains the same alkyl radical, the boiling-point of an amide is higher than that of the corresponding acid. Methyl alcohol boils at 66°, methylamine at —6°, acetic acid at 118°, acetamide at 222°.

The general properties of amides can best be illustrated by a description of a typical member of the series.

178. Acetamide, $CH_3CO.NH_2$, is a colorless, crystalline solid which melts at 82° and boils at 222°. As ordinarily prepared it has an odor which is described as resembling that of the excrement of mice. When carefully purified it is odorless. It is readily soluble in water and in alcohol, and can be crystallized from benzene in which it dissolves to a less extent.

Acetamide may be most conveniently prepared by allowing a mixture of one volume of ethyl acetate and two volumes of concentrated ammonia to stand until a homogeneous solution is formed. The amide is obtained from the aqueous solution by distillation. The reaction which takes place is an example of a general reaction made use of in the preparation of other amides: —

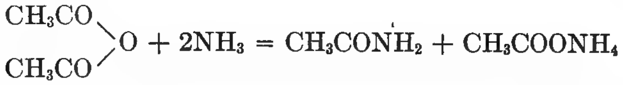
$$CH_3CO.OC_2H_5 + NH_3 = CH_3CO.NH_2 + C_2H_5OH.$$

Acetamide is formed by the action of acetyl chloride on ammonia. The reaction is analogous to that by which an amine is formed:

$$CH_3CO.Cl + 2NH_3 = CH_3CO.NH_2 + NH_4Cl$$
$$CH_3Cl + 2NH_3 = CH_3NH_2 + NH_4Cl$$

The difference in the rate at which the reaction takes place in the two cases is marked. In the case of the acyl chloride reaction takes place when the two substances are brought together at room temperature. It will be recalled, on the other hand, that in the preparation of amines by this reaction the alkyl halide is heated with ammonia at a high temperature to bring about the reaction. The introduction of a negative radical into ammonia, which is positive, is thus much more readily accomplished than the introduction of a positive radical.

Amides are also formed by the action of acid anhydrides on ammonia: —



$$\left.\begin{matrix}CH_3CO\\CH_3CO\end{matrix}\right>O + 2NH_3 = CH_3CONH_2 + CH_3COONH_4$$

The chlorides and anhydrides of acids yield, in most cases, the same substances with the various compounds with which they interact.

Acetamide and other members of this class can be prepared by heating the ammonium salts of the corresponding acids at a high temperature (200°–250°) in sealed tubes: —

$$CH_3COONH_4 = CH_3CO.NH_2 + H_2O$$

The most important reaction of amides is that which takes place when they are heated with water. Hydrolysis results, and the bond between carbon and nitrogen is broken. Acetamide, for example, is converted into ammonium acetate as the result of the formation of acetic acid and ammonia: —

$$CH_3CO.NH_2 + H.OH = CH_3CO.OH + NH_3$$

The rate of the reaction is markedly increased in the presence of acids or bases. As in the case of the hydrolysis of esters, the hydrogen and hydroxyl ions act as catalytic agents, — the hydroxyl ion effecting the hydrolysis more rapidly.

It is interesting to note that amines do not undergo a similar hydrolysis; methyl amine, for example, is not converted by alkalies into methyl alcohol and ammonia: —

$$CH_3NH_2 + HOH = CH_3OH + NH_3$$

It is difficult to break the bond which links carbon and nitrogen when the carbon atom is in a positive radical. When the radical is negative, however, the nitrogen may be removed in most cases as ammonia by hydrolysis.

When an amide is heated with a dehydrating agent, water is eliminated and a nitrile is formed. Acetonitrile can be prepared by distilling acetamide with phosphorus pentoxide; —

$$CH_3CONH_2 = CH_3CN + H_2O$$

Under proper conditions a nitrile may be converted into an amide.

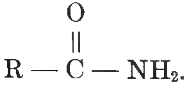
Like primary amines, the primary amides react with nitrous acid; in both cases the NH_2 group is replaced by OH: —

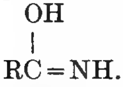
$$CH_3CONH_2 + HNO_2 = CH_3COOH + N_2 + H_2O$$
$$CH_2NH_2 + HNO_2 = CH_3OH + N_2 + H_2O$$

The reactions of the amides with hypobromites are analogous to those of the primary and secondary amines with this reagent; one or two atoms of hydrogen are replaced by bromine:

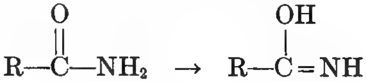
$$CH_3CONH_2 + Br_2 + KOH = CH_3CONHBr + KBr + H_2O$$
$$CH_3CONH_2 + 2Br_2 + 2KOH = CH_3CONBr_2 + 2KBr + 2H_2O$$

It will be remembered that the monobromamides are formed in the preparation of amines by Hofmann's reaction.

179. Structure of Amides. — The formation of amides from acid chlorides, esters, and cyanides can best be interpreted by assigning to the amides the structure  $R - \overset{\overset{\displaystyle O}{\|}}{C} - NH_2$. While most of the properties are in accord with this view of their structure, compounds of this class enter into certain reactions which are best interpreted by assuming that their structure is different from that given. Amides react with certain metallic oxides and form compounds which resemble salts. Acetamide and mercuric oxide, for example, form a compound of the composition $(CH_3CONH)_2Hg$. It appears probable from a study of the reactions of these compounds that the metallic atom which they contain is linked to oxygen. This view leads to the conclusion that the salts of the amides are derived from a compound the structure of which is represented by the formula,



$R\overset{OH}{\overset{|}{C}}=NH$. If this view is correct it is highly probable that an amide has the structure of an amino compound, but that during the process of salt formation a molecular rearrangement takes place as indicated by the formulas, —



$$R{-}\overset{O}{\overset{\|}{C}}{-}NH_2 \rightarrow R{-}\overset{OH}{\overset{|}{C}}=NH$$

AMIDES OF DIBASIC ACIDS

180. Urea, $CO(NH_2)_2$, is the amide of carbonic acid. It is sometimes called carbamide. It was first isolated from urine (whence its name) in which it occurs in relatively large quantities, as it is the chief waste nitrogenous substance formed as the result of the metabolism of foods. An adult excretes from 20 to 30 grams of urea per day. Urea may be isolated from urine by evaporating it to small bulk and adding concentrated nitric acid. The nitrate of urea, which precipitates, is recrystallized from moderately concentrated nitric acid to remove colored substances present. It is then dissolved in water and barium carbonate is added. The salt is decomposed, barium nitrate, carbon dioxide, and urea are formed. The solution is finally evaporated to dryness and the urea extracted with hot alcohol.

Urea crystallizes from water, in which it is readily soluble, in long prisms which melt at 132°. It can be prepared in a number of ways which furnish evidence of its structure. It is formed by the action of ammonia on carbonyl chloride, —

$$COCl_2 + 2NH_3 = CO(NH_2)_2 + 2HCl,$$

and on ethyl carbonate, —

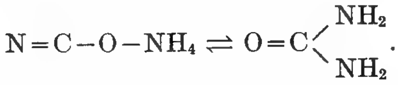
$$CO(OC_2H_5)_2 + 2NH_3 = CO(NH_2)_2 + 2C_2H_5OH.$$

Ammonium carbonate yields urea when heated in a sealed tube:

$$CO(NH_4)_2 = CO(NH_2)_2 + 2H_2O$$

It should be noted that in these ways of preparing urea, use has been made of reactions which are of general application in the preparation of amides.

Urea is formed when an aqueous solution of ammonium sulphate and potassium cyanate is evaporated. Ammonium cyanate is first formed, and then passes by intramolecular rearrangement into urea: —



$$N{=}C{-}O{-}NH_4 \rightleftharpoons O{=}C\begin{matrix} \diagup NH_2 \\ \diagdown NH_2 \end{matrix}.$$

This reaction is of particular interest as urea was first obtained in this way by Wöhler in 1828. The discovery of this synthesis of urea had a marked effect on the development of organic chemistry. It was the first example of the formation in the laboratory from so-called inorganic compounds of an organic compound produced in the body as the result of the vital force. The reaction by which urea is formed from ammonium cyanate has been shown to be a reversible one. Silver cyanate is precipitated when silver nitrate is added to a solution of urea in boiling water. The reaction has been investigated quantitatively in the study of the law of mass action.

Urea takes part in reactions which are characteristic of amides. When heated with an alkali it is hydrolyzed: —

$$CO(NH_2)_2 + H_2O = CO_2 + 2NH_3.$$

The same decomposition is effected by an organism known as *micrococcus ureae*, which causes the liberation of ammonia from urine which is allowed to stand for some time.

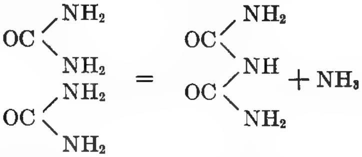
When urea is treated with sodium hypochlorite or sodium hypobromite, stable substitution-products are not formed as in the case of acetamide, but complete decomposition results. The reaction which takes place, in the main, according to the equation, —

$$CO(NH_2)_2 + 3NaOBr = N_2 + 3NaBr + CO_2 + 2H_2O,$$

is made use of in the determination of the urea content of urine. The volume of the nitrogen formed is a measure of the amount of urea present. The reaction between urea and nitrous acid is normal — carbonic acid and nitrogen are formed.

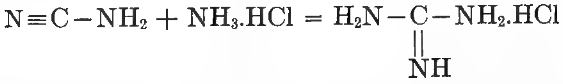
Urea resembles the amines in certain of its reactions, as the NH_2CO group which is in combination with the second NH_2 group in urea, $NH_2CO.NH_2$, is more positive than the acyl radicals. It forms salts with strong acids. The nitrate $CO(NH_2)_2.HNO_3$ and oxalate $2CO(NH_2)_2.(COOH)_2$, crystallize well. Urea, like methylamine, reacts with acetyl chloride and acetyl urea is formed, $CH_3CO.NH.CO.NH_2$. A number of such compounds, which are called ureids, are known.

181. When urea is heated it loses ammonia, and *biuret* is among the products formed: —

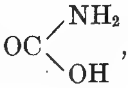


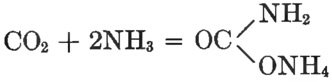
Biuret is a crystalline substance which melts at 190°. When it is treated with a solution of potassium hydroxide, or sodium hydroxide, which contains a trace of copper sulphate, a characteristic reddish-violet color appears. This is called the biuret reaction. The reaction is given by proteins, and is a useful test for these substances. Other substances which contain two $CONH_2$ groups linked together by a nitrogen or carbon atom, or by one or more CONH groups, give this test.

182. Guanidine is related to urea; its structure is represented by the formula, $HN=C(NH)_2$. The replacement of the oxygen atom in urea by the NH group has a marked effect on the properties of the resulting substance. Guanidine possesses strong basic properties; it is a colorless, crystalline substance, which absorbs moisture and carbon dioxide from the air. It is usually prepared by heating ammonium thiocyanate at 180°–185°. It is formed when cyanamide is heated with ammonium chloride:

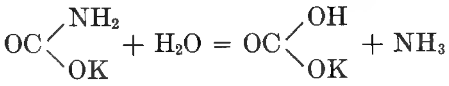


$$N{\equiv}C-NH_2 + NH_3.HCl = H_2N-\underset{\underset{NH}{\|}}{C}-NH_2.HCl$$

183. Carbamic Acid, , which may be considered as derived from carbonic acid by the replacement of one hydroxyl group by the amido group, is not known in the free condition. The ammonium salt of this acid is formed when carbon dioxide and ammonia are brought together: —



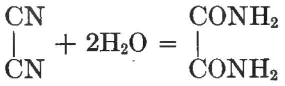
Ammonium carbamate is a constituent of commercial ammonium carbonate. The salts of carbamic acid are hydrolyzed by boiling with water, the reaction being analogous to that with other amides: —



184. Oxamide, $(CONH_2)_2$, is most readily prepared by shaking methyl or ethyl oxalate with concentrated ammonia: —

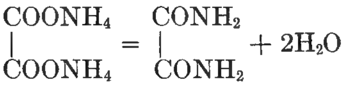
$$(COOC_2H_5)_2 + 2NH_3 = (CONH_2)_2 + 2C_2H_5OH$$

It is formed in the partial hydrolysis of cyanogen: —



$$\begin{array}{l}CN\\ |\\ CN\end{array} + 2H_2O = \begin{array}{l}CONH_2\\ |\\ CONH_2\end{array}$$

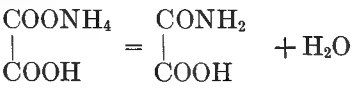
and when ammonium oxalate is heated: —



$$\begin{array}{l}COONH_4\\ |\\ COONH_4\end{array} = \begin{array}{l}CONH_2\\ |\\ CONH_2\end{array} + 2H_2O$$

It is a colorless crystalline powder which is insoluble in water. At about 180° it sublimes, without melting, with partial decomposition into cyanogen and water. When heated with water in the presence of acids or alkalies it is hydrolyzed, and oxalic acid and ammonia are formed.

When the acid ammonium salt of oxalic acid is heated, water is lost, as in the case of the neutral salt, and a compound called *oxamic acid* is obtained: —

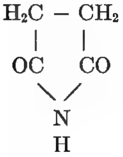


$$\begin{array}{l}COONH_4\\ |\\ COOH\end{array} = \begin{array}{l}CONH_2\\ |\\ COOH\end{array} + H_2O$$

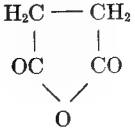
Analogous compounds may be obtained from other dibasic acids: thus, succinamic acid, $\begin{array}{l}CH_2CONH_2\\ |\\ CH_2COOH\end{array}$, may be prepared from succinic acid, $(CH_2COOH)_2$. Substitution-products of succinamic acid and similar compounds are important constituents of certain plants. Some of these will be described later.

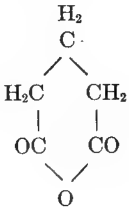
185. **Succinamide**, $(CH_2CONH_2)_2$, is prepared from ethyl succinate and ammonia. It is a crystalline substance, which melts at 242°–243°, and is sparingly soluble in water. The reactions of succinamide are, in general, analogous to those of oxamide. When heated to a high temperature, however, it is not converted into the corresponding nitrile and water, but by the loss of one molecule of ~~the latter~~ NH_3 passes into *succinimide* $(CH_2CO)_2NH$.

The formation of imides takes place in the case of dibasic acids which contain a straight chain of four or five carbon atoms. In the resulting compounds the atoms are arranged in what is called a "ring." The graphic formula of succinimide may be written in a way which makes this clear: —

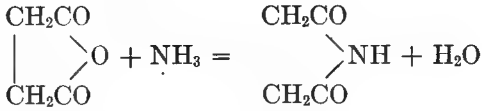


The tendency for atoms to arrange themselves in rings which contain five or six atoms is marked, and many compounds of the greatest importance possess this kind of structure. It will be recalled that dibasic acids which contain four or five carbon atoms readily pass into anhydrides with the formation of ring compounds containing five or six atoms in the ring. The anhydrides of succinic and glutaric acids have the structure represented by the formulas: —

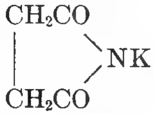




Succinimide is formed when succinic anhydride is heated in a stream of dry ammonia: —



It is readily soluble in water, from which it crystallizes with one molecule of water. The anhydrous imide melts at 126° and boils at 287°–288°. Although succinimide has a neutral reaction and does not decompose carbonates, it forms salts in which one hydrogen is replaced by a metallic atom. Potassium hydroxide and succinimide react in alcoholic solution to form a salt to which the formula



is assigned.

186. Identification of Amides. — The reaction of primary amides which is of the most importance in their identification, is that which takes place when they are heated with alkalies. If a substance has been found to contain nitrogen, it should first be tested to determine whether it is an amine, a salt of an amine, or an ammonium salt. Amines or ammonia will be set free from their salts when they are treated with a *cold* solution of sodium hydroxide. If no reaction takes place the substance should be heated with a boiling solution of the alkali. Under these conditions an amide is decomposed and ammonia is liberated, which is recognized by its odor. Substituted amides, like methyl acetamide, $CH_3CO.NHCH_3$, yield substituted ammonias.

Nitriles also yield ammonia when boiled with a solution of an alkali. The test is, therefore, not conclusive. The physical properties of the two classes of compounds are different, and are, thus, helpful in their identification. The amides of the fatty acids are solids which boil at comparatively high temperatures. They are also, in most cases, heavier than water. The nitriles of these acids, on the other hand, are, except those of a very high molecular weight, liquids of comparatively low boiling-point. The nitriles are lighter than water.

To complete the identification, the melting-point or boiling-point of the amide is determined. It is often helpful to determine both of these constants as an aid in the identification of amides and other substances. The conclusion arrived at should be verified by converting the amide into another compound, and determining its physical properties. The amides of monobasic acids may be conveniently converted into nitriles, and those of the dibasic acids into the corresponding acids.

PROBLEMS

1. Summarize in the form of equations (*a*) the methods of preparing amines and amides, (*b*) the general reactions of amines and amides, and (*c*) the characteristic reactions of the three classes of amines.

2. Write equations for reactions by which substances of the following compositions may be prepared: (*a*) $CH_3.C_2H_5.C_3H_7N$, (*b*) $CH_3CO.NHC_3H_7$, (*c*) $C_3H_7CO.NHCH_3$, (*d*) $(CH_3)_3C_2H_5NOH$, (*e*) $(C_4H_9)_2NCl$, (*f*) $(C_4H_9)_4NCl$.

3. Write equations for reactions by which (*a*) choline, and (*b*) putrescine may be prepared from methyl and ethyl alcohols.

4. Write equations for reactions by which (*a*) ethyl alcohol may be converted into methyl alcohol, (*b*) acetamide into ethyl amine, (*c*) acetic acid into ethyl alcohol.

5. By what chemical reactions could the following be distinguished from each other: (*a*) $CH_2Br.CH_2NH_2$ and $CH_3.CH_2.NH_2.HBr$, (*b*) $C_3H_7NH_2$ and $(CH_3)_3N$, (*c*) CH_3NH_2 and CH_3CONH_2, (*d*) $CH_3CO.NHCH_3$ and $CH_3COO.NH_3CH_3$.

CHAPTER XII

CYANOGEN AND RELATED COMPOUNDS

187. Many organic compounds contain carbon united with nitrogen in such a way that in their chemical transformations these elements remain in combination, and thus pass from one compound to another. When organic substances were first investigated this phenomenon was observed, and the name radical (from *radix*, root) was given to this group of atoms (CN) and to others, which likewise passed unchanged from one compound to another.

It was shown that the composition and properties of many compounds containing the cyanogen radical were similar to those of the corresponding compounds which contained a halogen atom. The analogy between the two series of compounds is shown by the following formulas: —

$$\begin{array}{llllll} (CN)_2 & HCN & KCN & Hg(CN)_2 & HCNO & CH_3CN \\ Cl_2 & HCl & KCl & HgCl_2 & HClO & CH_3Cl \end{array}$$

This relation indicated that a group of elements could play the part of an atom. The first attempt made to solve the mystery of complex organic compounds was directed toward the discovery of the radicals which they contained. This was the beginning of the structure theory of organic chemistry.

The cyanogen radical which may be introduced into many compounds is present in potassium cyanide, from which such compounds are prepared. Only the more important substances which contain this radical will be described here.

188. Cyanogen, $(CN)_2$, is formed in small quantity when nitrogen is passed over an electric arc formed between carbon poles, and when ammonium oxalate is heated: —

$$(COONH_4)_2 = (CN)_2 + 4H_2O$$

It may be prepared by heating the cyanide of silver or of mercury: —

$$Hg(CN)_2 = Hg + (CN)_2$$

There is formed at the same time a brown amorphous substance, called paracyanogen, to which the formula $(CN)_x$ is assigned. It is a polymer of cyanogen of unknown molecular weight, which is converted into cyanogen by heating at a high temperature.

Cyanogen is more conveniently prepared by warming an aqueous solution of copper sulphate and potassium cyanide. A double decomposition between the two salts results in the formation of cupric cyanide and potassium sulphate. The former, at a comparatively low temperature, decomposes with the formation of cuprous cyanide and cyanogen. The reactions are expressed by the equations, —

$$CuSO_4 + 2KCN = K_2SO_4 + Cu(CN)_2$$
$$2Cu(CN)_2 = 2CuCN + (CN)_2$$

These reactions are analogous to those which take place between copper sulphate and potassium iodide in aqueous solution. It will be recalled that cuprous iodide and iodine are formed.

Cyanogen is a colorless gas, which can be condensed to a liquid boiling at −20.7°. It possesses a peculiar, pungent odor, and is excessively poisonous. It burns with a blue flame surrounded by a rose-pink mantle. Cyanogen is moderately soluble in water; the aqueous solution is unstable, and, on standing, deposits a brown amorphous substance of unknown structure, called azulminic acid; the solution then contains ammonium oxalate and other substances. The formation of cyanogen from ammonium oxalate and the change in the reverse direction, indicates that cyanogen is the nitrile of oxalic acid: —

$$\begin{matrix} C\equiv N \\ | \\ C\equiv N \end{matrix} + 4H_2O \rightleftharpoons \begin{matrix} COONH_4 \\ | \\ COONH_4 \end{matrix}$$

Cyanogen is absorbed by a solution of potassium hydroxide, the reaction which takes place being analogous to that between the alkali and a halogen: —

$$2KOH + Cl_2 = KCl + KClO + H_2O$$
$$2KOH + (CN)_2 = KCN + KCNO + H_2O$$

189. Cyanogen Chloride, CN.Cl, is formed by the action of chlorine on an aqueous solution of hydrocyanic acid: —

$$H{-}C\equiv N + Cl_2 = Cl{-}C\equiv N + HCl$$

It is a colorless, very poisonous liquid, which boils at 15.5°. It polymerizes readily to cyanuric chloride, $C_3N_3Cl_3$, a solid which melts at 146°. Cyanogen chloride and ammonia interact to form cyanamide: —

$$CN.Cl + 2NH_3 = CN.NH_2 + NH_4Cl$$

190. Cyanamide, $CN.NH_2$, is a crystalline, hygroscopic solid, which polymerizes readily. Like other compounds in which the amido group is in combination with a negative radical, metallic derivatives may be formed by the replacement of the hydrogen atoms. Silver cyanamide, $CN.NAg_2$, is a yellow amorphous substance which, unlike most silver salts, is insoluble in ammonia.

When lime and carbon are heated to a red heat in an atmosphere of nitrogen, calcium cyanamide is formed as the result of the action of nitrogen on the calcium carbide first produced: —

$$CaC_2 + N_2 = CN.NCa + C$$

Calcium cyanamide is decomposed slowly by water and ammonia is formed: —

$$CN.NCa + 3H_2O = 2NH_3 + CaCO_3$$

This and other reactions of cyanamide and its derivatives indicate that the compound is the amide of cyanic acid, $N \equiv C - OH$. The decomposition of calcium cyanamide can be explained on this assumption. Hydrolysis first yields cyanamide which, like other amides, is converted by water into an acid and ammonia: —

$$CN.NCa + 2H_2O = CN.NH_2 + Ca(OH)_2$$
$$CN.NH_2 + H_2O = CN.OH + NH_3$$

Cyanic acid reacts rapidly with water and forms ammonia and carbon dioxide, which in this case would convert the calcium hydroxide formed into a carbonate: —

$$CNOH + H_2O = NH_3 + CO_2$$

Calcium cyanamide is made on the commercial scale, and is being used as a fertilizer. The substance is of special interest as by means of it atmospheric nitrogen may be changed into a form (ammonia) in which it serves as a plant food.

When barium carbide is heated in nitrogen, barium cyanide is formed: —

$$BaC_2 + N_2 = Ba(CN)_2$$

The reaction furnishes a means of preparing cyanides from atmospheric nitrogen.

191. Hydrocyanic Acid, HCN, commonly called prussic acid, occurs in the free condition in certain plants. It is formed as the result of the decomposition of a substance called amygdalin (**285**), which occurs in the leaves of the cherry and laurel, in bitter almonds, peach stones, and other substances.

Hydrocyanic acid is a colorless liquid which boils at 26°, and when cooled forms crystals which melt at – 14°. It has an odor similar to that of the oil of bitter almonds. It burns with a pale blue flame. Hydrocyanic acid is one of the most powerful poisons; 0.05 gram is said to be a fatal dose. Inhalation of hydrogen peroxide or air containing chlorine is said to be an antidote for hydrocyanic acid. The poisonous property of the acid is in some way associated with the $\overline{CN}$ ion. Substances from which this ion is produced are poisonous, whereas those, like potassium ferrocyanide, which do not give a simple $\overline{CN}$ ion are not poisonous.

Hydrocyanic acid is readily soluble in water; the solution is unstable and deposits on standing a brown amorphous substance. Ammonium formate is among the products of the decomposition. Hydrocyanic acid thus appears to be the nitrile of formic acid: —

$$H{-}C{\equiv}N + 2H_2O = H.COONH_4$$

The reaction will take place in the direction opposite to that written, as hydrocyanic acid is formed when ammonium formate is heated.

The acid is prepared by distilling potassium cyanide or potassium ferrocyanide with a dilute solution of sulphuric acid: —

$$KCN + H_2SO_4 = KHSO_4 + HCN$$

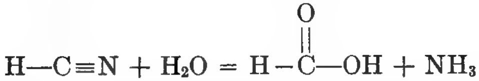
The anhydrous acid is obtained from the solution prepared in this way by fractional distillation.

Hydrocyanic acid is a very weak acid; it scarcely reddens blue litmus. It reacts with hydroxides but not with carbonates. The cyanides are decomposed by carbonic acid. The soluble salts — those of the alkali metals, the alkaline-earth metals, and mercuric cyanide — may be made by the interaction of the acid and bases, the insoluble ones by double decomposition.

192. The *structure of hydrocyanic acid* is deduced from its reactions. On reduction it yields methyl amine: —

$$H—C\equiv N + 4H = CH_3NH_2$$

and on hydrolysis formic acid and ammonia: —



$$H—C\equiv N + H_2O = H-\overset{\overset{\displaystyle O}{\|}}{C}—OH + NH_3$$

These reactions can be interpreted best on the assumption that in the acid the hydrogen atom is joined to carbon. Hydrocyanic acid appears to bear the same relation to formic acid that methyl cyanide, CH_3CN, bears to acetic acid, $CH_3.COOH$, and it is shown below that methyl cyanide has the structure represented by the formula $H_3C–C\equiv N$ in which the methyl group is in combination with carbon.

Another arrangement of the atoms in hydrocyanic acid is possible, however, namely, that in which the hydrogen atom is linked to nitrogen, $H-NC$. Some of the properties of hydrocyanic acid are in accord with this view of its structure. The cyanogen radical, $-C\equiv N$, is strongly electro-negative. When introduced into a compound it has even a greater effect on the negative nature of the molecule than chlorine. It will be shown later that chloracetic acid, $CH_2Cl.COOH$, is a much stronger acid than acetic acid, and that cyanacetic acid, $CH_2CN.COOH$, is, in turn, stronger than chloracetic acid. The CH_2CN- radical is thus more negative than the $CH_2Cl.-$ group. From this point of view it appears remarkable that hydrocyanic acid, $H-CN$, is such a weak acid, whereas hydrochloric acid, $H-Cl$, is one of the strongest of acids. It is possible, therefore, that hydrocyanic acid may have the structure $H-NC$, or that it is a mixture of the two forms, $H-NC \rightleftharpoons H-CN$.

193. Potassium Cyanide, KCN, is formed when potassium burns in cyanogen, and when nitrogen is passed into a mixture of carbon and fused potassium carbonate. It is prepared by strongly heating potassium ferrocyanide: —

$$K_4Fe(CN)_6 = 4KCN + FeC_2 + N_2$$

As one-third of the nitrogen is lost in the reaction, the ferrocyanide is frequently fused with sodium: —

$$K_4Fe(CN)_6 + 2Na = 4KCN + 2NaCN + Fe$$

The mixture of cyanides finds applications in the industries. It is used in the extraction of gold from its ores.

Potassium cyanide crystallizes in colorless plates, is readily soluble in water, and very slightly soluble in alcohol. It is an active poison. The aqueous solution is unstable; among the products formed on standing are potassium formate and ammonia. Fused potassium cyanide is a powerful reducing agent; it is used to effect the reduction of metallic oxides: —

$$PbO + KCN = Pb + KCNO$$

The insoluble cyanides dissolve in solutions of potassium cyanide, and double salts are formed. These belong to two classes: those which are readily decomposed by dilute acids in the cold and yield hydrocyanic acid, and those which yield complex acids. When, for example, the double salt of the formula $KAg(CN)_2$ is treated with an acid, silver cyanide is precipitated and hydrocyanic acid is formed as the result of the action of the acid on potassium cyanide. When, however, potassium ferrocyanide, $K_4Fe(CN)_6$, is treated with an acid, a simple double decomposition takes place and hydroferrocyanic acid is formed: —

$$K_4Fe(CN)_6 + 4HCl = 4KCl + H_4Fe(CN)_6$$

The double cyanides of gold, nickel, and silver are used in electroplating. When the double salt of the composition $KAg(CN)_2$ is dissolved in water, decomposition into its constituents does not take place, but the salt ionizes according to the equation, —

$$KAg(CN)_2 \rightleftharpoons \overset{+}{K} + \overset{-}{Ag(CN)_2}$$

It has been found that silver and gold produced as the result of the decomposition of the complex ions is deposited more evenly than that deposited from the simple metallic ion. The double salts are, accordingly, used in plating.

The soluble salts of hydrocyanic acid are hydrolyzed in aqueous solution, and, consequently, show an alkaline reaction: —

$$KCN + HOH \rightleftharpoons KOH + HCN$$

194. Potassium ferrocyanide, $K_4Fe(CN)_6.3H_2O$, yellow prussiate of potash, may be formed by dissolving ferrous hydroxide in potassium cyanide: —

$$Fe(OH)_2 + 2KCN = 2KOH + Fe(CN)_2$$
$$Fe(CN)_2 + 4KCN = K_4Fe(CN)_6$$

It is manufactured by heating to a high temperature a mixture of potassium carbonate, scrap iron, and refuse animal material, such as horn shavings, hair, leather scraps, and blood. After cooling, the fused mass is extracted with water, filtered, and the solution evaporated to crystallization. Potassium ferrocyanide is also prepared on the commercial scale from the spent iron oxide from the purification of illuminating gas. It is used for making potassium cyanide, Prussian blue, and potassium ferricyanide; in calico printing and in dyeing; and as a reagent. When distilled with dilute sulphuric acid it is decomposed and hydrocyanic acid is formed; at a higher temperature, with a stronger acid (about 90 per cent H_2SO_4), carbon monoxide is produced. The decomposition serves as a convenient way to prepare this gas. The reaction consists in the hydrolysis of hydrocyanic acid to formic acid and the dehydration of the latter: —

$$K_4Fe(CN)_6 + 3H_2SO_4 = 2K_2SO_4 + FeSO_4 + 6HCN$$
$$HCN + 2H_2O = HCOOH + NH_3$$
$$HCOOH + H_2SO_4 = CO + H_2SO_4.H_2O$$

When potassium ferrocyanide is added to a solution of a ferric salt, a characteristic blue precipitate, called Prussian blue, is formed: —

$$3K_4Fe(CN)_6 + 4FeCl_3 = Fe_4[Fe(CN)_6]_3 + 12KCl$$

The reaction is one of double decomposition by which insoluble ferric ferrocyanide is formed.

195. Potassium Ferricyanide, $K_3Fe(CN)_6$, red prussiate of potash, crystallizes in anhydrous blood-red prisms. It is prepared by the action of an oxidizing agent on potassium ferrocyanide. Chlorine is usually used. The gas is passed into the solution of the ferrocyanide until oxidation is complete. This is shown by testing the solution with ferric chloride, when, if any ferrocyanide is present, Prussian blue will be formed. Ferric chloride and potassium ferricyanide produce a brown color. The equation for the oxidation is: —

$$2K_4Fe(CN)_6 + Cl_2 = 2KCl + 2K_3Fe(CN)_6$$

An alkaline solution of potassium ferricyanide is an oxidizing agent, and is used in calico printing. The salt is also used in making *blue-print paper*, which is prepared by coating paper with a solution of potassium ferricyanide and a ferric salt which is rapidly reduced by sunlight. Ferric ammonium citrate is generally used for this purpose, as the salt of an organic acid is more sensitive to light than one of an inorganic acid. This increased sensitiveness is due to the fact that the acid radical present readily undergoes oxidation and thus assists in the reduction of the iron. When paper so prepared is exposed to light, the ferric citrate is reduced to a ferrous salt. On treatment with water, the ferrous compound formed on the parts of the paper which were exposed to the action of light, interacts with the potassium ferricyanide and Turnbull's blue is formed. No reaction takes place where the paper has not been exposed, and, on washing, the soluble salts are removed and the original color of the paper appears.

ALKYL CYANIDES

196. When potassium cyanide is heated with an alkyl halide, a reaction takes place that is analogous to many with which the student is familiar. The metal and the halogen unite to form a salt, and the radicals to form an organic compound: —

$$KCN + RI = KI + RCN$$

The substances prepared in this way are called cyanides or nitriles. The name of a particular member of this class is determined by the radical in combination with the CN group. Thus, CH_3CN is methyl cyanide or acetonitrile, and C_2H_5CN is ethyl cyanide or propionitrile. The prefix added to nitrile is derived from the name of the acid into which the nitrile passes on hydrolysis.

The nitriles of lower molecular weight are colorless liquids, which boil at atmospheric pressure without decomposition.

They are soluble in water, but the solubility decreases with increasing molecular weight; octyl cyanide, $C_8H_{17}CN$, is almost insoluble in water. The nitriles which contain sixteen or more carbon atoms are crystalline solids. They all are lighter than water, the specific gravity varying between 0.78 and 0.90.

197. Methyl Cyanide, CH_3CN, may be considered as a representative of the class. It is a liquid of strong but not unpleasant odor, which boils at 81°. It is formed by boiling a solution of methyl iodide and potassium cyanide in alcohol diluted with water. The reaction takes place slowly. It is best prepared by distilling ammonium acetate, or, better, acetamide, with phosphorus pentoxide: —

$$CH_3CONH_2 + P_2O_5 = CH_3CN + 2HPO_3$$

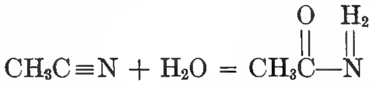
Nitriles, in general, may be prepared by analogous reactions, and by distilling a dry mixture of potassium cyanide and a salt of an alkyl sulphuric acid: —

$$KCN + C_2H_5SO_4K = K_2SO_4 + C_2H_5CN$$

When boiled with a solution of an acid or an alkali, the nitriles are hydrolyzed; acids and ammonia result: —

$$CH_3CN + 2H_2O = CH_3COOH + NH_3$$

When they are heated with water alone, however, to a high temperature, they interact with a smaller proportion of water and an amide is formed: —



$$CH_3C{\equiv}N + H_2O = CH_3\overset{\overset{\displaystyle O}{\|}}{C}{-}\overset{\overset{\displaystyle H_2}{\|}}{N}$$

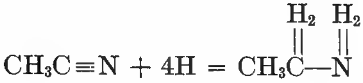
The addition of water is made possible by the unsaturated nature of the linking between the carbon and nitrogen atoms in the CN radical. In the case of certain nitriles the reaction takes place rapidly when they are gently heated with a solution of hydrogen peroxide which contains some potassium hydroxide:

$$C_5H_{11}CN + 2H_2O_2 = C_5H_{11}CO.NH_2 + H_2O + O_2$$

This method is frequently of service in the preparation of amides from nitriles.

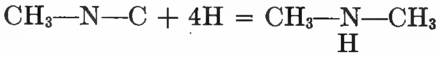
It should be noted that in the hydrolysis of the cyanides the reaction which takes place is not of the same nature as the hydrolysis of esters; methyl cyanide, for example, does not yield methyl alcohol and hydrocyanic acid.

Nitriles are reduced by nascent hydrogen to primary amines; methyl cyanide yields ethylamine: —



$$CH_3C\equiv N + 4H = CH_3\overset{H_2}{\overset{\|}{C}}-\overset{H_2}{\overset{\|}{N}}$$

This reaction indicates that in methyl cyanide the alkyl radical is joined to carbon, for if it had the structure represented by the formula $CH_3-N\equiv C$, in which the carbon atoms are joined through nitrogen, we should expect to get on reduction, dimethylamine, in which the carbon atoms are so joined: —



$$CH_3-N-C + 4H = CH_3-\underset{H}{N}-CH_3$$

The fact that the hydrolysis of nitriles leads to the formation of ammonia and acids which contain the same number of carbon atoms as the nitrile, is strong evidence in favor of the view that in these compounds the nitrogen atom is at the end of the chain.

Alkyl Isocyanides

198. When an alkyl halide is treated with silver cyanide, reaction takes place in the usual way; a silver halide and an organic compound are formed. The product, however, is not an alkyl cyanide, as is the case when potassium cyanide is used, but an isomeric compound. The substances prepared from silver cyanide are called isocyanides, isonitriles, or carbylamines. The last name is given to them on account of the fact that they unite with acids and thus resemble the amines. The addition-products do not, however, resemble salts in their chemical properties. When hydrogen chloride is passed into an ethereal solution of methyl isocyanide, a compound of the formula $2CH_3NC.3HCl$ is formed, which is decomposed when brought into contact with water.

The isocyanides are colorless liquids, which are sparingly soluble in water, and possess a disagreeable, almost unbearable odor. They are lighter than water. The boiling-point of a cyanide is higher than its isomer which contains the same number of carbon atoms; thus, ethyl cyanide boils at 97° and ethyl isocyanide at 78°. The difference in the physical and chemical properties of cyanides and isocyanides is attributed to a difference in structure. It has been shown that the reactions of the cyanides lead to the view that in them the alkyl radicals are in combination with carbon, $R-CN$. On the other hand, the reactions of isocyanides can best be explained on the assumption that the radical is joined to nitrogen, $R-NC$. A study of the chemical properties of methyl isocyanide will make clear the reasons for this statement.

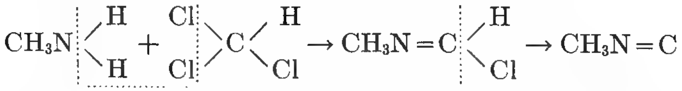
Methyl Isocyanide, CH_3NC, is formed by heating methyl iodide with silver cyanide: —

$$CH_3I + AgNC = CH_3NC + AgI$$

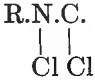
As some methyl cyanide is formed in the reaction, the substance is best prepared by heating methylamine with an alcoholic solution of chloroform and potassium hydroxide (carbylamine reaction, section **164**): —

$$CH_3NH_2 + CHCl_3 + 3KOH = CH_3NC + 3KCl + 3H_2O$$

This reaction, which serves as a general method of preparing isocyanides, throws some light on their structure. In the primary amines the alkyl group is in combination with nitrogen, and it seems probable that in their change to isocyanides this union remains intact. The reaction is best explained on the view that is represented by the following formulas: —

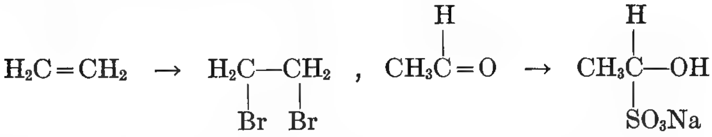


This reaction, while it indicates that in the isocyanides the alkyl group is joined to nitrogen, does not make clear the nature of the union between nitrogen and carbon. Should the graphic symbol be written $CH_3-N=C$ or $CH_3N\equiv C$? According to the first formula carbon is represented as having the valence two. It was assumed for a long time that in all organic compounds carbon showed a constant valence of four, but the result of the study of the reactions of isocyanides and other substances has led to the view that the properties of these compounds can best be explained on the assumption that they contain a bivalent carbon atom. The evidence is clear in the case of the isocyanides. Certain of these compounds unite with two atoms of chlorine and form addition-products: $RNC.Cl_2$. If the union is possible as the result of a state of unsaturation between the nitrogen and carbon atom, the structure of the addition-product should be represented by the formula, —



$$\begin{array}{c}R.\underset{\displaystyle Cl}{\underset{|}{N}}.\underset{\displaystyle Cl}{\underset{|}{C}}.\end{array}$$

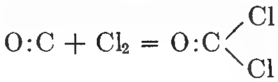
It will be recalled that when addition takes place to unsaturated compounds which are represented as containing a double or triple bond, the reaction takes place in such a way that atoms or groups are added to the adjacent atoms between which the state of unsaturation exists. This is represented by the formulas which are already familiar: —



$$H_2C=CH_2 \rightarrow H_2\underset{\displaystyle Br}{\underset{|}{C}}—\underset{\displaystyle Br}{\underset{|}{C}}H_2\ , \quad CH_3\overset{\displaystyle H}{\overset{|}{C}}=O \rightarrow CH_3\overset{\displaystyle H}{\overset{|}{\underset{\displaystyle SO_3Na}{\underset{|}{C}}}}—OH$$

When chlorine is added to an isocyanide, however, the two atoms unite directly with carbon. The structure of the addition-products must be represented by the formula $RNC\begin{matrix}\diagup Cl\\ \diagdown Cl\end{matrix}$. This is shown by the fact that when these addition-products are treated with silver oxide the halogen atoms are replaced by oxygen and an isocyanate, $R-N=C=O$, is formed. The structure of the isocyanates has been established by a study of their properties. It follows, therefore, that in the isocyanides the unsaturation must be traced to a *single* element and is not, as in most cases, the result of a mutual relation between two elements. The formula may be written, therefore, $R-N=C=$, to emphasize the fact that the carbon atom is unsaturated. It is written, however, $R-N=C$ and the carbon is said to be bivalent. Unsaturation of a single element is common in inorganic chemistry. In phosphorus trichloride, for example, phosphorus is unsaturated in that it can unite with two chlorine atoms and form phosphorus pentachloride. Such compounds are rarely, however, spoken of as unsaturated. The distinction is drawn by assigning different valences to the atoms in the different compounds. Thus phosphorus trichloride is $P\equiv Cl_3$, and phosphorus is said to be trivalent; in the pentachloride it is pentavalent.

Many reactions of organic compounds can best be interpreted by the assumption that carbon may, under certain circumstances, exist in the bivalent condition. We have a striking case in carbon monoxide. Although the graphic symbol of this compound may be written $C\equiv O$, its properties are better in accord with the view that it contains a bivalent carbon atom, $C=O$. For example, it reacts with chlorine and forms carbonyl chloride in which the chlorine atoms are joined to carbon: —



$$O{:}C + Cl_2 = O{:}C\begin{smallmatrix}\diagup Cl\\ \diagdown Cl\end{smallmatrix}$$

It is true that recent work in organic chemistry has lead to the discovery of compounds in which oxygen shows a valence of four, and the formula $C\equiv O$ is not unreasonable, therefore. Nevertheless, the view that in carbon monoxide carbon is bivalent is more in accord with the facts.

CYANIC ACID AND RELATED COMPOUNDS

199. Cyanic Acid, $H-O-C\equiv N$ or $H-N=C=O$, is prepared by heating cyanuric acid, which is described below, and condensing the gas formed in a freezing mixture: —

$$H_3O_3C_3N_3 = 3HOCN$$

It is a strongly acid, unstable liquid, which polymerizes rapidly above 0° to a substance called cyamelide. As the aqueous solution of the acid decomposes into carbon dioxide and ammonia, —

$$HONC + H_2O = NH_3 + CO_2$$

it can not be prepared by the action of an acid on a cyanate.

200. Potassium Cyanate, KOCN, is formed by the slow oxidation of potassium cyanide in the air. It is prepared by heating potassium cyanide with lead oxide: —

$$KCN + PbO = KOCN + Pb$$

When the reaction is complete the cyanate is extracted from the mass by dilute alcohol. On evaporation it is obtained as a crystalline powder which is readily soluble in water. In aqueous solution the salt is hydrolyzed: —

$$KOCN + 2H_2O = NH_3 + KHCO_3$$

It will be recalled that ammonium cyanate spontaneously rearranges into urea (**180**).

201. Cyanuric Acid, $(CNOH)_3$, is obtained by the action of water on cyanuric chloride, $C_3N_3Cl_3$, which results from the polymerization of cyanogen chloride, CNCl. It is also obtained when urea is heated to a high temperature: —

$$3CO(NH_2)_2 = (CNOH)_3 + 3NH_3$$

It is a crystalline, tribasic acid, and forms well-characterized salts.

202. Fulminic Acid, $C{=}N{-}OH$. — Salts of this acid are obtained when nitric acid, alcohol, and mercury or silver are brought together in certain proportions. Mercuric fulminate, $(CNO)_2Hg$, is prepared for use in percussion caps, which are used to explode gunpowder, dynamite, and other explosives. Free fulminic acid is a very unstable volatile liquid. It resembles closely hydrocyanic acid in odor and poisonous properties.

CHAPTER XIII

HALOGEN COMPOUNDS

203. The halogen derivatives of the hydrocarbons are of the greatest value in the synthesis of organic compounds. The methods of preparing these substances vary with the element or group to be replaced by the halogen atom, and with the element with which the latter is brought into combination. Their activity as determined by their ability to enter into reaction with other substances, is determined by the chemical nature of the group to which the halogen is joined. The halogen compounds thus illustrate many of the important principles of organic chemistry, and the effect of structure on chemical activity.

Alkyl Halides

The alkyl halides form an homologous series which is unusually complete. The physical properties of some of the halides which possess the normal structure are given in the following table: —

NORMAL ALKYL HALIDES

	Chloride		Bromide		Iodide	
	Boiling-point	Specific Gravity	Boiling-point	Specific Gravity	Boiling-point	Specific Gravity
Methyl	—23.7°	0.952(0°)	4.5°	1.732(0°)	45°	2.293(18°)
Ethyl	12.2°	0.918(8°)	38.4°	1.468(13°)	72.3°	1.944(14°)
Propyl	46.5°	0.912(0°)	71°	1.383(0°)	102.5°	1.786(0°)
Butyl	78°	0.907(0°)	101°	1.305(0°)	130°	1.643(0°)
Amyl	107°	0.901(0°)	129°	1.246(0°)	156°	1.543(0°)
Hexyl	133°	0.892(16°)	156°	1.193(0°)	182°	1.461(0°)
Heptyl	159°	0.881(16°)	179°	1.113(16°)	201°	1.386(16°)
Octyl	180°	0.880(16°)	199°	1.116(16°)	221°	1.345(16°)

It is seen that the boiling-points increase with increasing molecular weight, and for the halides with a given number of carbon atoms, with the increase in the atomic weight of the halogen. The specific gravities of the chlorides are less than one, those of the bromides and iodides greater than one. The specific gravities of the compounds with any halogen decrease with increase in molecular weight. The alkyl halides are insoluble in water, but dissolve in alcohol and ether, with which the lower members are miscible in all proportions. They are insoluble in concentrated sulphuric acid, and have a sweetish odor. The halides are colorless, but as the iodides decompose slowly on standing, a sample of an iodide which has been kept for some time is colored brown by the dissolved iodine formed. The lower alkyl halides burn with a green flame.

The reactivity of the normal alkyl halides varies with the halogen and with the alkyl group; the more reactive are those with the smaller number of carbon atoms. The iodides are the most reactive, the chlorides the most inert. Methyl iodide is much used in organic syntheses, as it reacts readily with many substances and serves as a means of introducing the methyl group into such compounds. An alcoholic solution of methyl iodide reacts with a similar solution of silver nitrate in the cold, and silver iodide is formed. With ethyl iodide the reaction proceeds much more slowly, and with the higher alkyl iodides the application of heat is necessary to bring about reaction.

The great difference in chemical properties between the organic and inorganic halogen compounds has been emphasized. It was stated that the most marked difference between the two classes is observed when they are treated with water. The halides of the metals are ionized when they are dissolved in water; the organic compounds are not ionized. It is possible that the difference observed is one of degree only. The alkyl halides, for example, may undergo electrolytic dissociation, but the extent of the dissociation is so slight that it can not be measured by the methods commonly employed to detect this phenomenon, such as electrical conductivity, effect on freezing-point, and so forth. There is good reason for the belief that such dissociation takes place — in fact a derivative of methyl bromide $(C_6H_5)_3C.Br$, has been prepared which in certain solvents conducts the electric current — but experimental work has not advanced far enough to warrant any conclusion as to whether electrolytic dissociation is an important factor in most reactions which take place between organic compounds.

In the following table are given the physical properties of the isomeric butyl halides: —

Radical in Combination with Halogen	CHLORIDE		BROMIDE		IODIDE	
	Boiling-point	Specific Gravity	Boiling-point	Specific Gravity	Boiling-point	Specific Gravity
Prim. Norm. Butyl	78°	0.907(0°)	101°	1.305(0°)	130°	1.643(0°)
Isobutyl	68.5°	0.895(0°)	92°	1.204(16°)	119°	1.640(0°)
Sec.-Butyl	67.5	0.871(20°)	91.3°	1.250(25°)	119°–120°	1.626(0°)
Tert.-Butyl	55°	0.866(0°)	72°	1.215(20°)	100°	1.571(0°)

The effect of structure on the boiling-point is clearly shown. The halides which contain the tertiary radicals boil at the lowest temperatures, and have the smallest specific gravities.

204. Preparation of Alkyl Halides. — The members of the three classes of alkyl halides — those which contain primary, secondary, and tertiary radicals, respectively, — may be prepared, in general, by the same methods, although the method which is best adapted to a particular case often varies with the class to which the halide belongs.

Primary alkyl halides of low molecular weight may be prepared by the action of the gaseous halogen acids on the alcohols in the presence of a dehydrating agent. Ethyl chloride, for example, is prepared most conveniently by passing hydrogen chloride into alcohol in which anhydrous zinc chloride is dissolved. The chloride, which is a gas, is freed from hydrochloric acid by passing it through water. This method can not be applied in the case of the higher alcohols which are readily dehydrated. The zinc chloride converts the alcohol into an unsaturated hydrocarbon, which unites with the halogen hydride and forms a halide of a secondary radical. The reactions in case of nonyl alcohol are shown by the following equations: —

$$C_7H_{15}.CH_2.CH_2.OH \overset{ZnCl_2}{=} C_7H_{15}.CH:CH_2 + H_2O$$
$$C_7H_{15}CH:CH_2 + HCl = C_7H_{15}.CHCl.CH_3$$

It is convenient in some cases to set free the acid from a salt in the presence of the alcohol. Ethyl bromide, for example, is conveniently prepared by distilling a mixture of alcohol, potassium bromide, and sulphuric acid. It is evident that this method is limited in its application to those alcohols which are not readily converted into unsaturated hydrocarbons by sulphuric acid.

The bromides and iodides are conveniently prepared by distilling an alcohol with an excess of an aqueous solution of hydrobromic acid and hydriodic acid. The chlorides which contain primary alkyl groups can not be made in this way. The reactions of the alcohols with aqueous solutions of the halogen acids have been described (**49**, **61**).

The method of replacing a hydroxyl group by a halogen atom which is most general in its application, is that in which the compound containing this group is treated with a halide of phosphorus. These reactions have also been described (**57**). It should be noted that reactions take place other than those which lead to the formation of the alkyl halide. In the preparation of alkyl bromides and iodides by this method it is not necessary to use halides of phosphorus, which have been prepared previously. Red phosphorus is added to the alcohol, and bromine or iodine is then cautiously added. The phosphorus halide formed interacts with the alcohol. After standing for some time the mixture is distilled. Ethyl iodide is conveniently prepared in this way.

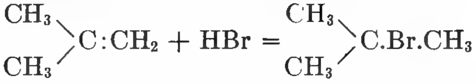
The secondary alkyl halides can be prepared from the alcohols by the action of the halogen acids or the phosphorus halides. In certain cases they can be made by adding the halogen hydride to unsaturated hydrocarbons. Addition takes place most readily with hydriodic acid. Secondary butyl iodide, for example, can be prepared in this way from butylene and hydriodic acid: —

$$CH_3.CH_2.CH{:}CH_2 + HI = CH_3.CH_2.CHI.CH_3$$

Certain secondary alkyl halides are most readily prepared from polyatomic alcohols. The formation of isopropyl iodide from glycerol has been noted (**74**). Secondary hexyl iodide is prepared in the same way from mannitol. The equations for the two reactions are:—

$$CH_2OH.CHOH.CH_2OH + 5HI = CH_3.CHI.CH_3 + 2I_2 + 3H_2O$$
$$CH_2OH(CHOH)_4CH_2OH + 11HI = CH_3(CH_2)_3CHICH_3 + 5I_2 + 6H_2O$$

The tertiary alkyl halides are most readily prepared by the addition of the halogen acids to unsaturated hydrocarbons. Tertiary butyl bromide, for example, may be formed by the addition of hydrobromic acid to isobutylene:—

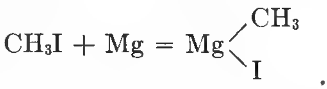


$$\begin{matrix}CH_3\\CH_3\end{matrix}\!\!>C{:}CH_2 + HBr = \begin{matrix}CH_3\\CH_3\end{matrix}\!\!>C.Br.CH_3$$

Alkyl chlorides or bromides are formed as the result of the action of chlorine or bromine on the paraffins, but the reaction is not used in the preparation of these compounds. In general, a mixture of substitution-products is obtained. Thus pentane with chlorine yields chlorides of the structure $CH_3(CH_2)_3CH_2Cl$ and $CH_3(CH_2)_2CHCl.CH_3$ together with other substitution-products. The replacement of hydrogen joined to carbon by chlorine or bromine is facilitated by sunlight and catalytic agents. Iodine does not react with the paraffins (**18**).

205. Reactions of Alkyl Halides. — Halogen atoms in organic compounds enter into reactions with many substances. When the alkyl halides are brought into contact with the more active metals, the halogen atom either is removed and a condensation-product formed, or addition takes place. The two classes of reactions are illustrated by those which take place between methyl iodide and sodium and magnesium:—

$$2CH_3I + 2Na = CH_3—CH_3 + 2NaI$$

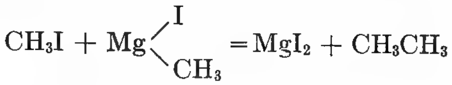


$$CH_3I + Mg = Mg\!<\!\begin{matrix}CH_3\\I\end{matrix} .$$

Reactions of these types are of importance. The first (Wurtz reaction) is used in the preparation of hydrocarbons; the second is the first step in many important syntheses (Grignard's reaction).

The alkyl halides react not only with metals in the free condition, but when they are present in compounds. Many such reactions have been discussed. The equations for a few are repeated here: —

$$
\begin{aligned}
CH_3I + NaOH &= NaI + CH_3OH \\
CH_3I + NaOCH_3 &= NaI + CH_3OCH_3 \\
CH_3I + NaOOC.CH_3 &= NaI + CH_3OOC.CH_3 \\
CH_3I + AgNO_2 &= AgI + CH_3.NO_2 \\
CH_3I + KCN &= KI + CH_3CN \\
CH_3I + CHNa(COOC_2H_5) &= NaI + CH_3.CH(COOC_2H_5)_2
\end{aligned}
$$



$$CH_3I + Mg\begin{matrix} \diagup I \\ \diagdown CH_3 \end{matrix} = MgI_2 + CH_3CH_3$$

The halides react with water: —

$$CH_3I + HOH = CH_3OH + HI$$

They are converted into unsaturated hydrocarbons when heated with a base; a solution of potassium hydroxide in alcohol is frequently used: —

$$C_2H_5I = C_2H_4 + HI$$

They form addition-products with ammonia and the amines: —

$$
\begin{gathered}
CH_3I + NH_3 = CH_3NH_3I \\
CH_3I + N(CH_3)_3 = (CH_3)_4NI
\end{gathered}
$$

The reactions of tertiary halides are frequently different from those of the corresponding primary compounds. The former are readily converted into unsaturated hydrocarbons as the result of the elimination of hydrogen halide. Thus, tertiary butyl iodide when heated with ammonia does not form an amine as normal butyl iodide does, but is converted into isobutylene. The effect of the positive or negative nature of the group in combination with a halogen atom on its reactivity when brought into contact with other compounds, will be considered in the discussion of acyl halides (**218**, **220**).

206. Identification of Alkyl Halides. — On account of their inertness the alkyl halides are usually identified by their inability to enter into reactions at ordinary temperatures. They are insoluble in concentrated sulphuric acid, and, unlike the acyl halides, they do not react readily with water and alcohols. Unlike the compounds in which halogen is joined to nitrogen, they are not easily changed by an aqueous solution of sodium hydroxide. They are distinguished from many halogen derivatives of benzene and related hydrocarbons, which will be described later, by the fact that they are decomposed when boiled with an alcoholic solution of potassium hydroxide: —

$$C_2H_5Br + KOH(\text{in alcohol}) = C_2H_4 + KBr + H_2O$$

The presence of halogen ions, from the salt formed, may be shown by adding silver nitrate to the diluted solution after it has been acidified by the addition of nitric acid.

The specific gravity of a halide is frequently determined, as this constant, considered in connection with the boiling-point of a substance, often serves to identify it. The specific gravities of the chlorine derivatives of the fatty hydrocarbons which contain one chlorine atom, are less than one. Those of the derivatives which contain more than one chlorine atom are greater than one. The accumulation of halogen atoms in a compound results in an increase in specific gravity. Thus this constant for ethyl bromide, C_2H_5Br, is 1.468 (13°), and for ethylene bromide, $C_2H_4Br_2$, 2.189 (15°).

UNSATURATED HALOGEN COMPOUNDS

207. The substitution-products of the unsaturated hydrocarbons may be sharply divided into two classes according to their chemical properties. Those in which the halogen is joined to a saturated carbon atom form one class, and those in which it is joined to a carbon atom linked to a second carbon atom by a double or triple bond, form another. The structure of such compounds is illustrated by the isomeric brompropylenes: —

$CH_2=CH.CH_2Br$	$CH_2=CBr.CH_3$	$CHBr=CH.CH_3$
1-brompropylene	2-brompropylene	3-brompropylene

1-Brompropylene (allyl bromide), may be formed by the methods used in the preparation of the alkyl bromides. It resembles the bromides of the saturated radicals in its conduct with other compounds. It differs from them, however, in that it is much more reactive. The other brompropylenes belong to the second class. They are comparatively inert and do not enter into reactions of double decomposition with other substances. The characteristic properties of the unsaturated halides can be illustrated best by a consideration of a few typical members.

208. Vinyl bromide, $CH_2{=}CHBr$, is prepared by the action of alcoholic potash upon ethylene bromide: —

$$CH_2Br.CH_2Br + KOH(\text{in alcohol}) = CH_2{:}CHBr + KBr + H_2O$$

It is a liquid of ethereal odor, which boils at 16°, and has the specific gravity 1.517 at 14°. It is polymerized by the action of sunlight into a white mass which is insoluble in alcohol and ether. It shows but few of the reactions which are characteristic of the saturated halogen compounds. When treated with an aqueous solution of an alkali, an alcohol is not formed; sodium ethylate does not yield an ether, nor sodium acetate an ester. With all these reagents vinyl bromide loses hydrogen bromide and acetylene is formed: —

$$CH_2{:}CHBr = CH{\vdots}CH + HBr$$

209. 1-Brompropylene (allyl bromide), $CH_2{=}CH.CH_2Br$, can be prepared by treating allyl alcohol with hydrobromic acid or phosphorus tribromide. It boils at 71°, and has the specific gravity 1.459 (0°). Allyl bromide enters into reaction readily with the different classes of compounds with which alkyl bromides react. The activity of the unsaturated halides of this type, as measured by the rate at which reaction with other substances proceeds, is much greater than that of the saturated halides. For example, the rate at which allyl iodide reacts with sodium ethylate to form an ether is 60 times that at which propyl iodide reacts with the same substance.

210. 2-Brompropylene, $CH_2{=}CBr.CH_3$, (b.p. 48°), like other substances of this class, can be prepared from a halogen derivative of a saturated hydrocarbon, by applying the general method of preparing unsaturated compounds. It is formed from the dibrompropane of the structure $CH_3.CBr_2.CH_3$ by eliminating one molecule of hydrobromic acid: —

$$CH_3.CBr_2.CH_3 = CH_2{:}CBr.CH_3 + HBr$$

It does not enter into reactions of double decomposition, and does not add to unsaturated compounds.

3-Brompropylene, $CH_3CH=CHBr$, (b.p. 60°), resembles 2-brompropylene in chemical properties. It is prepared from 1,1-dibrompropane: —

$$CH_3.CH_2.CHBr_2 = CH_3.CH:CHBr + HBr$$

When propylene bromide is treated with alcoholic potash a mixture of 2- and 3-brompropylene is obtained: —

$$CH_3.CHBr.CH_2Br = CH_3.CH:CHBr + HBr$$
$$CH_3.CHBr.CH_2Br = CH_3.CBr:CH_2 + HBr$$

The halogen substitution-products of the hydrocarbons of the acetylene series resemble those derived from hydrocarbons which contain a double bond. The derivatives of acetylene are very unstable. Chloracetylene is a gas which decomposes instantaneously, with explosion. The substitution-products which contain the $\equiv CH$ group form precipitates with ammoniacal solutions of silver and cuprous salts.

SUBSTITUTION-PRODUCTS OF THE HYDROCARBONS WHICH CONTAIN MORE THAN ONE HALOGEN ATOM

211. Many compounds of this class are known. A variety of methods are used in their preparation, some of the more important of which will be discussed in the consideration of a few typical compounds. The reactions of the polyhalogen derivatives of the hydrocarbons resemble, to some extent, those of the monohalogen substitution-products. The accumulation of negative atoms in the molecule modifies, however, the reactivity of these compounds. The position of a halogen atom relative to a second halogen atom is a determining factor in the influence of the one on the reactivity of the other. Thus, while ethylene bromide, $CH_2Br.CH_2Br$, reacts more readily with other substances than does ethyl bromide, $CH_3.CH_2Br$, ethylidene bromide, $CH_3.CHBr_2$, is relatively inert and does not enter, in general, into reactions of double decomposition. In most cases the accumulation of halogen atoms about a single carbon atom leads to inertness, while the reverse is true if the halogen atoms are linked to different atoms. It would lead too far at this point to describe in detail many polyhalogen compounds, but a comparative study of the properties of these in relation to their structure might well be undertaken with profit. Some of the derivatives of methane and ethane which illustrate important principles, will be discussed.

POLYHALOGEN DERIVATIVES OF THE HYDROCARBONS
C_nH_{2n+2}

Name	Formula	Melting-point	Boiling-point	Specific Gravity
Methylene chloride	CH_2Cl_2	—	40°	1.337(15°)
Methylene bromide	CH_2Br_2	—	98.5°	2.498(15°)
Methylene iodide	CH_2I_2	4°	180°	3.292(18°)
Chloroform	$CHCl_3$	—70°	61°	1.498(15°)
Bromoform	$CHBr_3$	7.8°	151°	2.904(15°)
Iodoform	CHI_3	119°	—	—
Carbon tetrachloride	CCl_4	—24.7°	76°	1.593(20°)
Carbon tetrabromide	CBr_4	92°	189°	—
Ethylene chloride	$CH_2Cl.CH_2Cl$	—	83.7°	1.260(15°)
Ethylene bromide	$CH_2Br.CH_2Br$	8.4°	132°	2.189(15°)
Ethylidene bromide	$CH_3.CHBr_2$	—	110.5°	2.082(21.5°)
Propylene bromide	$CH_3.CHBr.CH_2Br$	—	142°	1.944(15°)
1, 1–Dibrompropane	$CH_3.CH_2.CHBr_2$	—	130°	—
2, 2–Dibrompropane	$CH_3.CBr_2.CH_3$	—	115°	1.848(15°)
1, 3–Dibrompropane	$CH_2Br.CH_2.CH_2Br$	—	165°	1.974(17°)

212. Methylene Chloride, CH_2Cl_2, dichlormethane, is formed when chlorine acts upon methane in the sunlight. As it can not be obtained pure in this way, it is prepared from chloroform by replacing one halogen atom by hydrogen. The replacement is effected by treating an alcoholic solution of chloroform with zinc and hydrochloric acid: —

$$CHCl_3 + 2H = CH_2Cl_2 + HCl$$

Methylene Iodide, CH_2I_2, is of interest on account of the fact that its specific gravity (3.292 at 18°) is greater than that of any other liquid. It is used in separating minerals of different specific gravities. By dilution with benzene, liquids of any desired specific gravity between that of benzene, 0.8736 $\frac{20^\circ}{4^\circ}$, and methylene iodide may be obtained. Methylene iodide is prepared by heating iodoform with hydriodic acid and phosphorus:

$$CHI_3 + HI = CH_2I_2 + I_2$$

Phosphorus is usually added when reductions are effected by hydriodic acid. It combines with the iodine liberated to form phosphorus iodide, which is converted by the water present into hydriodic acid and phosphoric acid. In this way hydriodic acid is constantly regenerated.

213. Chloroform, $CHCl_3$, trichlormethane, is prepared by distilling an aqueous solution of alcohol or acetone with bleaching powder. The reaction is a complex one, which is assumed to involve, in the case of alcohol, first, oxidation to aldehyde, then, substitution by which trichloraldehyde is formed, and, finally, decomposition of the latter which produces chloroform. It will be recalled that when bleaching powder is dissolved in water the solution reacts as if it contained calcium hypochlorite and calcium chloride. The steps in the reaction between alcohol and bleaching powder may be represented by the following equations: —

$$2CH_3.CH_2OH + Ca(OCl)_2 = 2CH_3.CHO + CaCl_2 + 2H_2O$$
$$2CH_3.CHO + 3Ca(OCl)_2 = 2CCl_3.CHO + 3Ca(OH)_2$$
$$2CCl_3.CHO + Ca(OH)_2 = 2CHCl_3 + (HCOO)_2Ca$$

It is possible that the reaction does not take place as indicated by the equations given above, as compounds other than chloroform are obtained. It is known, however, that when alcohol is treated with chlorine, trichloraldehyde is formed, and that the latter with alkalies yields chloroform and a salt of formic acid.

Chloroform is formed also when acetone is distilled with bleaching powder: —

$$2CH_3COCH_3 + 3Ca(OCl)_2 = 2CCl_3COCH_3 + 3Ca(OH)_2$$
$$2CCl_3COCH_3 + Ca(OH)_2 = 2CHCl_3 + (CH_3COO)_2Ca$$

The reaction, in all probability, takes place as indicated, as chloroform and calcium acetate are produced — the products formed when trichloracetone is treated with calcium hydroxide.

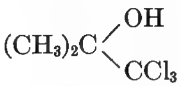
The formation of chloroform from acetone is an example of a general reaction. Ketones which contain the acetyl radical, CH_3CO, are converted by bleaching powder into chloroform and the salt of an acid; thus, methyl ethyl ketone yields chloroform and a propionate: —

$$2CH_3COC_2H_5 + 3Ca(OCl)_2 = CCl_3COC_2H_5 + 3Ca(OH)_2$$
$$2CCl_3COC_2H_5 + Ca(OH)_2 = 2CHCl_3 + (C_2H_5COO)_2Ca$$

Chloroform is a liquid, which possesses a characteristic ethereal odor and a sweet taste. It boils at 61°, and when solidified melts at $-70°$. It is only very slightly soluble in water: one liter of a saturated solution contains about seven grams of chloroform. It is not inflammable. Chloroform was formerly much used as an anæsthetic, but it has been replaced largely for this purpose by ether.

Chloroform is an excellent solvent for many organic substances. It dissolves rubber and fats, and is a useful cleansing agent.

A compound of chloroform and acetone, known in pharmacy as chloretone, is used as an hypnotic. It is formed from chloroform and acetone in the presence of potassium hydroxide. The structure of the addition-product is probably analogous to that of other such derivatives of acetone:

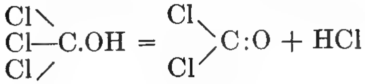


$$(CH_3)_2C\begin{matrix}\diagup OH \\ \diagdown CCl_3\end{matrix}$$

Chloroform slowly undergoes decomposition when exposed to air and light. Among the products formed are chlorine, hydrochloric acid, and carbonyl chloride, $COCl_2$. The presence of about one per cent of alcohol prevents, to a large extent, the decomposition.

Chloroform undergoes oxidation when heated with a mixture of sulphuric acid and potassium bichromate. The reaction serves as a means of preparing carbonyl chloride (phosgene) $COCl_2$: —

$$Cl_3CH + O = Cl_3C—OH$$



$$\begin{matrix}Cl\diagdown \\ Cl—C.OH \\ Cl\diagup\end{matrix} = \begin{matrix}Cl\diagdown \\ \\ Cl\diagup\end{matrix}C:O + HCl$$

214. Iodoform, CHI_3, tri-iodomethane, is formed when alcohol and certain other compounds (**57**) are treated with iodine in the presence of an alkali. It can be prepared by adding iodine to a warm aqueous solution of alcohol which contains sodium carbonate. The iodoform, which separates as a yellow precipitate, is purified by crystallization from dilute alcohol. It crystallizes in yellow, lustrous, six-sided plates, which melt at 119°, and have a peculiar, very characteristic odor. The reactions by which alcohol is converted into iodoform are analogous to those as the result of which chloroform is obtained from alcohol. The formation of iodoform is often used as a test for ethyl alcohol, but as other substances, such as acetone, isopropyl alcohol, and aldehyde yield iodoform when warmed in alkaline solution with iodine, the test is not reliable unless it is known that the other substances which respond to it are absent. Most of the compounds which yield iodoform when treated in this way contain the group $CH_3.C$ linked to oxygen.

Iodoform is used in surgery as an antiseptic. On account of its unpleasant odor many antiseptic preparations have been prepared in which the odor of iodoform, which most of them contain, is either disguised or eliminated. Eka-iodoform is a mixture of iodoform and paraformaldehyde; anozel, of iodoform and thymol. The so-called "di-iodoform" is tetra-iodo-ethylene, C_2I_4.

215. Carbon Tetrachloride, CCl_4, is the final product of the action of chlorine on methane. It is a heavy liquid which has a pleasant odor resembling that of chloroform. It boils at 76.7°, and has the specific gravity 1.593 at 20°. It is prepared commercially by the action of chlorine on carbon bisulphide in the presence of antimony pentasulphide, which acts as a carrier: —

$$CS_2 + 3Cl_2 = CCl_4 + S_2Cl_2$$

Carbon tetrachloride is an excellent solvent; mixed with gasoline or benzine it is much used for cleaning purposes. The mixture, owing to the presence of the halogen compound, is not inflammable.

216. Substitution-products of the Homologues of Methane.— The substitution-products of the homologues of methane which contain two halogen atoms may be divided according to their structure into three classes: those in which the halogen atoms are linked to the same carbon atom, such as the compounds with the structure,

$$CH_3.CHCl_2 \text{ and } CH_3.CCl_2.CH_3$$

those in which the halogen atoms are linked to neighboring carbon atoms, such as, —

$$CH_2Cl.CH_2Cl \text{ and } CH_3.CHCl.CH_2Cl$$

and, finally, those in which the atoms linked to halogen are separated by one or more carbon atoms as in

$$CH_3Cl.CH_2.CH_2Cl$$

Compounds of the first class are usually prepared by the action of the halides of phosphorus on aldehydes or ketones. Ethylidene chloride (1,1-dichlorethane) is prepared from aldehyde in this way: —

$$CH_3CHO + PCl_5 = CH_3CHCl_2 + POCl_3$$

and 2,2-dichlorpropane from acetone: —

$$CH_3COCH_3 + PCl_5 = CH_3CCl_2CH_3 + POCl_3$$

Most of the compounds of this class are not very reactive, and are not much used in synthetic work. Some of them readily lose halogen hydride. Those of high molecular weight undergo this decomposition on distillation. In the preparation of 2,2-dichlorpropane from acetone some 2-chlorpropylene is obtained: —

$$CH_3.CCl_2.CH_3 = CH_3.CCl{:}CH_2 + HCl$$

Ethylene Bromide, $C_2H_4Br_2$. — The compounds in which the halogen is linked to neighboring carbon atoms are much used in the synthesis of other compounds, as they readily undergo reactions of double decomposition. They are most conveniently prepared by adding the halogens to unsaturated hydrocarbons. When ethylene, for example, is passed through bromine, addition takes place and ethylene bromide is formed: —

$$CH_2{:}CH_2 + Br_2 = CH_2Br.CH_2Br$$

When zinc is added to an alcoholic solution of ethylene bromide, ethylene is rapidly evolved: —

$$CH_2Br.CH_2Br + Zn = ZnBr_2 + CH_2{:}CH_2$$

When boiled with an aqueous solution of potassium hydroxide, vinyl bromide and glycol are formed: —

$$CH_2Br.CH_2Br + KOH = CH_2{:}CHBr + KBr + H_2O$$
$$CH_2Br.CH_2Br + 2KOH = CH_2OH.CH_2OH + 2KBr + H_2O$$

When the reaction is carried out in alcoholic solution, some acetylene is also formed: —

$$CH_2Br.CH_2Br + 2KOH = CH{\equiv}CH + 2KBr + H_2O$$

Ethylene bromide reacts slowly with boiling water to form glycol: —

$$CH_2Br.CH_2Br + 2HOH = CH_2OH.CH_2OH$$

It should be noted that these reactions are analogous to those which take place between alkyl halides and water and alkalies. The effect of the presence of two halogen atoms is to make it possible for the reactions to take place much more rapidly and at a lower temperature. Other reactions in which ethylene bromide resembles the alkyl halides are those which take place with ammonia and potassium cyanide: —

$$CH_2Br.CH_2Br + 2NH_3 = CH_2NH_2.CH_2NH_2.2HBr$$
$$CH_2Br.CH_2Br + 2KCN = CH_2CN.CH_2CN + 2KBr$$

In this way diamines and the nitriles of dibasic acids may be prepared.

217. Trimethylene Bromide, 1,3-dibrompropane, $CH_2Br.CH_2.CH_2Br$, and other members of this class are prepared by adding halogen acids to unsaturated compounds. When allyl bromide is treated with hydrobromic acid two compounds are formed: —

$$CH_2{:}CH.CH_2Br + HBr = CH_2Br.CH_2.CH_2Br$$
$$CH_2{:}CH.CH_2Br + HBr = CH_3.CHBr.CH_2Br$$

The relation between the quantities of trimethylene bromide and propylene bromide obtained is determined by the concentration of the acid and the temperature at which the reaction is carried out. With a saturated aqueous solution of hydrobromic acid, and at a temperature below 30°, the product formed consists largely of 1,3-dibrompropane. Trimethylene bromide enters into reactions of double decomposition; for example, with water it yields trimethylene glycol, $CH_2OH.CH_2 CH_2OH$.

Acyl Halides

218. When the organic acids are treated with the halides of phosphorus the hydroxyl group which they contain is replaced by a halogen atom. The compounds formed react readily with other substances, and are much used in synthetic work and in the study of the structure of substances of unknown constitution. The acyl chlorides are used for these purposes and not the iodides as in the case of the alkyl halides. The chlorides are very reactive substances. The bromides and iodides are of minor importance, and have not been very fully investigated.

The first member of the series of acid chlorides is acetyl chloride, CH_3COCl. Formyl chloride is not known. When an attempt is made to prepare it by the reactions which yield acyl chlorides carbon monoxide and hydrochloric acid are obtained: —

$$H.COCl = HCl + CO$$

Physical Properties of Acyl Chlorides. — Acetyl chloride and its homologues with small molecular weight are colorless liquids of penetrating odor, which fume in the air as the result of the formation of hydrogen chloride. The acyl chlorides boil at a lower temperature than the corresponding acids from which they are prepared. Thus, the boiling-point of acetyl chloride is 51° and of acetic acid 118°. The replacement of the hydroxyl group in an alcohol by chlorine produces a similar effect on the boiling-point. Ethyl alcohol boils at 78°, ethyl chloride at $-12.2°$. The chlorides of high molecular weight can be distilled without decomposition only under diminished pressure. They are solids which may be crystallized from ether. Stearyl chloride melts at 23° and boils at 215° under a pressure of 15 mm. The acyl chlorides are insoluble in water, but those derived from the soluble acids rapidly pass into solution when treated with water, as the result of hydrolysis by which the acid and hydrochloric acid are formed.

219. Preparation of Acyl Chlorides. — Acetyl chloride and its homologues may be prepared by the action of phosphorus pentachloride on the fatty acids or their salts: —

$$CH_3COOH + PCl_5 = CH_3COCl + POCl_3 + HCl$$
$$CH_3COONa + PCl_5 = CH_3COCl + POCl_3 + NaCl$$

In the preparation of the chlorides of low molecular weight, phosphorus trichloride is usually employed as with this reagent phosphorus oxychloride, which is removed from these chlorides with difficulty on account of its low boiling-point, is not formed. Acetyl chloride is best prepared by heating a mixture of glacial acetic acid and phosphorus trichloride at about 40° until reaction is complete. This is shown by the separation of the mixture into two layers. The product is then distilled from a water bath, and the distillate is finally redistilled. The reaction takes place essentially according to the equation, —

$$3CH_3COOH + PCl_3 = 3CH_3COCl + P(OH)_3$$

Secondary reactions take place which result in the formation of hydrogen chloride and of compounds which contain the acetyl group in combination with phosphorus.

Acetyl chloride may also be prepared from anhydrous sodium acetate by treating it with phosphorus trichloride or phosphorus oxychloride. The salt is often used instead of the glacial acid on account of the fact that it can be more readily prepared and is, consequently, less expensive. The reactions which take place are shown by the following equations: —

$$3CH_3COONa + PCl_3 = 3CH_3COCl + Na_3PO_3$$
$$2CH_3COONa + POCl_3 = 2CH_3COCl + NaPO_3 + NaCl$$

In the technical preparation of acetyl chloride sulphuryl chloride, SO_2Cl_2, is used instead of the chlorides of phosphorus, on account of the cheapness of the sulphur compound. Acetyl chloride is prepared by passing a mixture of chlorine and sulphur dioxide over anhydrous sodium acetate. In the presence of the salt sulphuryl chloride is first formed.

220. Reactions of Acyl Chlorides. — Acetyl chloride and its homologues react readily with water, the reaction taking place with violence in the case of those of low molecular weight: —

$$CH_3CO.Cl + H.OH = CH_3CO.OH + HCl$$

In the ease with which this reaction takes place acyl chlorides are, in general, sharply distinguished from alkyl chlorides. The nature of the radical determines the rate at which the hydrolysis proceeds. The acyl chlorides, which contain negative radicals, resemble in their behavior with water the chlorides of the non-metallic or electro-negative elements, which react rapidly with water: —

$$PCl_3 + 3HOH = P(OH)_3 + 3HCl$$

It will be recalled that the alkyl halides enter into reaction with water but slowly, and that heating to a high temperature is required to effect the interchange of chlorine and hydroxyl with an appreciable speed.

Acyl chlorides react readily not only with water, but with substitution-products of water which contain a positive radical, that is, the alcohols. When acetyl chloride is mixed with alcohol, ethyl acetate and hydrochloric acid are formed: —

$$CH_3CO.Cl + HO.C_2H_5 = CH_3CO.OC_2H_5 + HCl$$

In this reaction the acyl chlorides are sharply differentiated from the alkyl chlorides which react with alcohols at high temperatures only.

Acetyl chloride serves, therefore, as a valuable reagent to determine the presence of alcoholic hydroxyl groups in organic compounds. The general reagent for the group — whether joined to a positive or negative radical — is phosphorus pentachloride. The number of hydroxyl groups in any compound may be determined by a quantitative study of the reaction which takes place when it is treated with these reagents. When phosphorus pentachloride is used, each hydroxyl group is replaced by one chlorine atom. With acetyl chloride the hydrogen of each alcoholic hydroxyl group is replaced by the acetyl radical.

Acetyl chloride does not react readily with a compound which contains a hydroxyl group in combination with an acyl radical. It does react, however, with salts of acids, the replacement of the hydrogen of the acid by the strongly positive metal making reaction possible. It will be recalled that the anhydrides of acids are made in this way: —

$$CH_3COCl + CH_3CO.ONa = (CH_3CO)_2O + NaCl$$

In view of the fact that acyl chlorides react with salts, it is remarkable that the halogen atoms which they contain can not be withdrawn by metals. Acetyl chloride does not react with sodium according to the equation, —

$$2CH_3COCl + 2Na = CH_3CO.COCH_3 + 2NaCl$$

While acyl radicals can not be brought into combination in this way, alkyl radicals can be so united.

Acyl chlorides react with ammonia and amines more readily than do the alkyl chlorides: —

$$CH_3COCl + NH_3 = CH_3CO.NH_2 + HCl$$
$$CH_3COCl + NH_2C_2H_5 = CH_3CONHC_2H_5 + HCl$$

Chlorides of Dibasic Acids

221. The compounds of this class are prepared by the methods which are used in the preparation of the chlorides derived from the fatty acids. In certain cases they are prepared by the action of phosphorus pentachloride on the anhydrides of the acids. In their reactions with other substances they resemble the chlorides of the monobasic acids.

Carbonyl Chloride, $CO.Cl_2$, phosgene, may be considered as the chloride of carbonic acid. It is prepared by oxidizing chloroform (**213**), or by passing a mixture of carbon monoxide and chlorine over charcoal. It was named phosgene by its discoverer on account of the fact that the union of the two substances was effected as the result of the influence of light. Carbonyl chloride is a gas with a powerful, stifling odor, which should be handled carefully as its inhalation produces most disagreeable effects. It can be easily condensed to a liquid which boils at 8.2° and has the specific gravity 1.432 at 0°. The gas is very soluble in benzene and toluene; such solutions are frequently used in synthetic work. Carbonyl chloride reacts slowly with cold water; carbon dioxide and hydrochloric acid are formed: —

$$COCl_2 + 2HOH = CO(OH)_2 + 2HCl$$

With alcohol reaction takes place in two steps: in the cold, chlorcarbonic ester, which is also called ethyl chloroformate, is formed: —

$$COCl_2 + HOC_2H_5 = ClCOOC_2H_5 + HCl$$

On long standing, or when carbonyl chloride is treated with sodium ethylate, both chlorine atoms interact and an ethereal salt of carbonic acid, ethyl carbonate, results: —

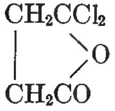
$$COCl_2 + 2HOC_2H_5 = CO(OC_2H_5)_2 + 2HCl$$

Carbonyl chloride and ammonia interact to form urea: —

$$CO.Cl_2 + 2NH_3 = CO(NH_2)_2 + 2HCl$$

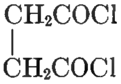
These reactions are characteristic of acid chlorides. They show that carbonyl chloride is the chloride of carbonic acid.

222. Succinyl Chloride is formed when succinic anhydride is treated with phosphorus pentachloride. The reactions of the compound indicate that its structure should be represented by the formula, —



(1)

The chloride may consist of a mixture of this compound and the normal one of the structure, —



$$\begin{array}{l} CH_2COCl \\ | \\ CH_2COCl \end{array}$$

(2)

Isomeric chlorides which have the unsymmetrical structure (formula 1) and the symmetrical structure (formula 2) have been isolated in the case of certain dibasic acids.

223. Identification of Acyl Chlorides. — The reactions of acyl chlorides which are most helpful in their identification, are those which take place when they are treated with water, with alcohol, and with ammonia. Reaction takes place readily with these substances. When an acyl chloride is mixed with a small quantity of water or alcohol, hydrogen chloride is evolved. In the case of certain chlorides gentle heat is necessary to bring about reaction. The physical properties of the chloride together with those of the acid, ester, or amide prepared from it serve to complete its identification.

Compounds which Contain a Halogen Joined to Nitrogen

224. The methods by which a halogen atom is brought into combination with nitrogen in an organic compound, are the same as those which are used to effect the union of these elements in inorganic compounds. Derivatives which contain trivalent nitrogen are prepared by treating ammonia with solutions of hypochlorites, hypobromites, or hypoiodites. Those which contain pentavalent nitrogen are formed by adding a halogen hydride to ammonia. Substitution-products and addition-products of the amines and amides are prepared in the same way from the derivatives of ammonia.

Methyl-dichloramine, CH_3NCl_2, is prepared by treating methylamine with bleaching-powder. It is a liquid, insoluble in water, which, like most compounds of this class, possesses a characteristic, disagreeable odor. It boils without decomposition at 59°–60°. This fact is of interest as nitrogen chloride, NCl_3, explodes violently when heated. The halogen is not converted into an ion when methyl-dichloramine is treated with water. The substance is readily decomposed by reagents. When heated with concentrated hydrochloric acid, for example, chlorine and methylammonium chloride are formed: —

$$CH_3NCl_2 + 3HCl = 2Cl_2 + CH_3NH_2HCl$$

Other members of this class of compounds take part in an analogous reaction, which is, therefore, of value in the identification of such substances.

225. Acetbromamide, $CH_3CO.NHBr$, is prepared by adding to a mixture of acetamide and bromine, in the proportion of their molecular weights, a 10 per cent solution of potassium hydroxide until a colorless solution is obtained. A hydrate of acetbromide separates in colorless crystals, $CH_3CONHBr.H_2O$. At 50° water is lost, and the anhydrous compound which melts at 108° is obtained. The substance is very reactive; ammonia and amines convert it into acetamide. Silver carbonate removes hydrogen bromide and methyl isocyanate is formed: —

$$CH_3CONHBr = CH_3NCO + HBr$$

When warmed with an aqueous solution of an alkali, acetbromamide is converted into methylamine (Hofmann's reaction): —

$$CH_3CONHBr + 3KOH = CH_3NH_2 + KBr + K_2CO_3 + H_2O$$

Acetdibromamide, CH_3CONBr_2, is obtained from acetbromamide by the action of bromine and sodium hydroxide. It forms golden yellow crystals, which melt at 100°; it undergoes decomposition when heated with water and is changed into acetamide.

The compounds which contain halogen in combination with pentavalent nitrogen have been described under the amines. They are salts which may be considered as substitution-products of ammonium halides. They ionize when dissolved in water, and, consequently, the halogen which they contain may be precipitated as silver halide when they are treated with a silver salt: —

$$(CH_3)_3NHCl + AgNO_3 = (CH_3)_3NHNO_3 + AgCl$$

This reaction serves to distinguish compounds of this class from other halogen substitution-products. Compounds which contain pentavalent nitrogen to which are linked one halogen and at least one hydrogen atom are decomposed in aqueous solution by bases: —

$$(CH_3)_3NHCl + KOH = KCl + H_2O + (CH_3)_3N$$

PROBLEMS

1. By what reagents can a hydrogen atom which is joined to (*a*) carbon and (*b*) nitrogen be replaced by chlorine?

2. Write equations for reactions (*a*) by which a hydrogen atom joined to carbon can be replaced by iodine, and (*b*) to illustrate the replacement of the hydroxyl group and oxygen by bromine.

3. Summarize, by writing equations, the reactions of saturated and unsaturated halogen compounds.

4. Show by equations how compounds containing the following groups may be prepared from saturated compounds: (*a*) $-CH=CBr-$, (*b*) $-CBr=CBr-$, (*c*) $-CHBr.CHBr-$, (*d*) $=CBr_2$, (*e*) $-CHBr.CH_2-$.

5. By what chemical test could you distinguish from each other (*a*) $CH_2=CH.CH_2Br$ and $CH_2=CBr.CH_3$, (*b*) $CH_2=CHBr$ and $CH_3.CH_2Br$, (*c*) CH_3COCl and C_3H_7Cl, (*d*) CH_3COCl and $CH_2Cl.COOH$, (*e*) $CH_2ClCOOCH_3$ and $CH_3COO.CH_2Cl$, (*f*) $(CH_2ClCO)_2O$ and $CH_3CO.Cl$.

CHAPTER XIV

COMPOUNDS CONTAINING TWO UNLIKE SUBSTITUENTS

226. In the previous chapters the preparation and properties of certain important classes of compounds have been discussed, and the principles which are illustrated in their transformations into one another have been emphasized. These principles are of wide application and can be employed in the preparation of compounds of more complex structure than any met with so far. For example, the method of preparing an alcohol by the treatment of an alkyl halide with water or an alkali, is very general in its application. The reaction consists in the replacement of a halogen atom by a hydroxyl group, and such replacement takes place not only with alkyl halides, but with other compounds which contain halogen. Thus, chloracetic acid can be transformed into hydroxyacetic acid by water: —

$$CH_2Cl.COOH + HOH = CH_2OH.COOH$$

The compound which results in this case contains a primary alcohol group (CH_2OH) and a carboxyl group ($COOH$). It is, thus, an alcohol and an acid, and in its behavior with other substances it shows the characteristic properties of both classes of compounds. It may be considered as derived from methyl alcohol by the replacement of one hydrogen atom by a carboxyl group. While the compound possesses many of the chemical properties of methyl alcohol, the replacement of a hydrogen atom by a carboxyl group leads to a modification in chemical activity which might be expected as the result of the replacement of a positive atom by a strongly negative group. In the same way, the replacement of hydrogen in acetic acid by the negative hydroxyl group renders the radical linked to carboxyl more negative, and, as a consequence, hydroxyacetic acid is a stronger acid than acetic acid, that is, it is more highly dissociated in aqueous solution.

By the application of the synthetic methods which have been described under the various classes of compounds, many substances which contain two or more unlike groups may be prepared. These compounds show the properties characteristic of the groups which they contain, but the mutual effect of one group on the activity of another in the same compound, brings about changes which are marked at times.

Many substances of the greatest importance contain two or more characteristic groups. The alcohol-acids occur in nature as constituents of fruits. The amine-acids and amide-acids occur in fruits and vegetables, and are important products of the decomposition of nitrogenous foods. Ketone-esters are much used in the preparation of other compounds. The ketone-alcohols and aldehyde-alcohols form the important class of substances known as carbohydrates. Only a few of the more important and typical mixed compounds will be considered here.

HALOGEN SUBSTITUTION-PRODUCTS OF THE ACIDS

227. Compounds of this class may be prepared by introducing halogen atoms into an acid, or the carboxyl group into halogen derivatives of the hydrocarbons. The former method is ordinarily used. Chloracetic and bromacetic acid, for example, may be prepared by the action of chlorine or bromine on acetic acid in the sunlight, or in the presence of a carrier (catalytic agent), such as iodine or sulphur: —

$$CH_3COOH + Cl_2 = CH_2Cl.COOH + HCl$$

Iodo-acetic acid can not be prepared from acetic acid and iodine. The compound is made by digesting a strong aqueous solution of chloracetic acid with potassium iodide.

As the introduction of a halogen into an acyl halide takes place more rapidly than into the acid itself, the substitution-products of the fatty acids are more conveniently prepared by the action of chlorine or bromine on these compounds. It is not necessary to isolate the latter; the acid to be brominated, for example, is mixed with red phosphorus, heated at about 80°, and bromine is slowly added. The phosphorus bromide first formed interacts with the acid to form the acyl bromide, which is converted by the free bromine present into a bromacyl bromide. The latter yields with water the halogen substitution-product of the acid: —

$$CH_3COOH \xrightarrow{PBr_3} CH_3CO.Br \xrightarrow{Br_2} CH_2Br.COBr \xrightarrow{H_2O} CH_2Br.COOH$$

The temperature at which the reaction is carried out, and the proportion of bromine used, determine the number of bromine atoms introduced. Thus, propionic acid when treated at 100° with phosphorus and bromine gives α-brompropionic acid, $CH_3CHBr.COOH$; and at 220° with an excess of bromine, α,α-dibrompropionic acid, $CH_3CBr_2.COOH$.

Direct chlorination or bromination of the fatty acids produces, in general, α-substitution-products. The acids which contain a halogen atom in the β-position are frequently prepared by adding a halogen hydride to an unsaturated acid. Thus, β-brompropionic acid is formed from acrylic acid and hydrobromic acid: —

$$CH_2{:}CH.COOH + HBr = CH_2Br.CH_2COOH$$

The addition takes place in this case according to the general principle which applies in most cases — the halogen adds itself to the more positive carbon atom. The α-carbon atom is rendered more or less negative by having in combination with it a carboxyl group.

Halogen-substituted acids are also prepared by the action of the halides of phosphorus on hydroxy-acids; hydroxyacetic acid, $CH_2OH.COOH$, for example, is converted into chloracetyl chloride by phosphorus pentachloride, both hydroxyl groups taking part in the reaction. The substituted acetyl chloride reacts readily with water and chloracetic acid and hydrochloric acid are formed: —

$$CH_2OH.COOH \xrightarrow{PCl_5} CH_2Cl.COCl \xrightarrow{H_2O} CH_2Cl.COOH$$

Derivatives of the acids which contain more than one halogen atom are prepared by substitution at high temperatures in the presence of a carrier or in the sunlight. They may also be formed by the addition of the halogens to unsaturated acids: —

$$CH_2{:}CH.COOH + Br_2 = CH_2Br.CHBr.COOH$$

228. Reactions of the Halogen Derivatives of the Fatty Acids. — The introduction of halogen atoms, which are negative, into the acids causes a marked increase in their strength. The relative effect of the three halogens, and of their position in the molecule on the strength of the acids, will be considered in detail in connection with other derivatives of the acids (**278**). On the other hand, the presence of the carboxyl group has a marked effect on the activity of the halogen atoms which these acids contain. The effect varies with the relative position of the halogen and the carboxyl group.

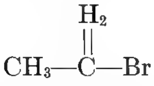
When an acid which contains a halogen atom in the *α*-position is boiled with an aqueous solution of an alkali, the halogen atom is readily replaced by hydroxyl: —

$$CH_3CHBr.COOH + 2KOH = CH_3CHOH.COOK + KBr + H_2O$$

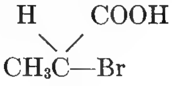
This reaction is analogous to that by which ethyl bromide is converted into alcohol: —

$$CH_3CH_2Br + KOH = CH_3CH_2OH + KBr$$

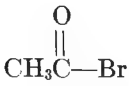
It differs from it, however, in that, while the alkyl halide must be heated for hours at a high temperature to effect the exchange of halogen for hydroxyl, the same transformation takes place with the halogen-substituted acid at a lower temperature and in less time. This difference is produced as the result of the presence of the negative carboxyl group. In the discussion of the relative reactivity of alkyl and acyl halides, it was pointed out that the marked difference between these two classes of compounds in this respect could be traced to the difference in the composition of the radicals which they contained. The replacement of two positive hydrogen atoms by one negative oxygen atom resulted in a marked change in properties. In the same way, we may consider *α*-brompropionic acid as derived from ethyl bromide by replacing one hydrogen atom by a carboxyl group. The formulas of the three compounds written to emphasize these relationships are as follows: —



$$CH_3—\overset{\overset{H_2}{\|}}{C}—Br$$



$$CH_3\overset{H\diagdown\ \diagup COOH}{C}—Br$$



$$CH_3\overset{\overset{O}{\|}}{C}—Br$$

From this point of view we should expect the reactivity of the halogen in the substituted acid to stand somewhere between that of the halogen in the alkyl halide and that in the acyl halide.

When the halogen atom in an acid is in the β-position, the compound yields, when heated with water or alkalies, a hydroxy acid, an unsaturated acid, or a hydrocarbon. In certain cases all three substances are formed. It is sometimes possible, by selecting the proper reagents, to vary the proportions in which the resulting substances are formed. When the acids are heated with water or with an alcoholic solution of potassium hydroxide, the chief product is an unsaturated acid: —

$$CH_3.CHBr.CH_2COOH = CH_3.CH{:}CH.COOH + HBr$$

On the other hand, when they are warmed with a solution of an alkali carbonate, an unsaturated hydrocarbon is also formed: —

$$CH_3.CHBr.CH(CH_3)COONa = CH_3.CH{:}CH.CH_3 + NaBr + CO_2$$

All of these reactions are analogous to ones which have been described, namely, the replacement of halogen by hydroxyl, the formation of an unsaturated compound by elimination of halogen hydride, and the decomposition of a salt of a fatty acid with the resulting formation of a hydrocarbon. This last decomposition takes place in the case of the fatty acids only on heating their salts to a comparatively high temperature with an alkali: —

$$CH_3COONa + NaOH = CH_4 + Na_2CO_3$$

It is seen in the case of the β-halogen-substituted acids, that an analogous decomposition takes place in water solution at or below the boiling-point. Other acids which contain groups more negative than the alkyl radicals undergo a similar decomposition very readily. For example, when trichloracetic acid is boiled with water, chloroform is formed: —

$$CCl_3COOH = CCl_3H + CO_2$$

The γ-halogen-substituted acids react readily with boiling water and form first, hydroxy acids, which, being unstable, lose one molecule of water and pass into substances known as lactones (**236**).

A brief description of only a few typical halogen-substituted acids will be given to emphasize the principles which have been set forth.

229. Chloracetic Acid, $CH_2Cl.COOH$, is prepared by the chlorination of acetic acid, acetyl chloride, or acetic anhydride in direct sunlight in the presence of iodine, which acts as a halogen-carrier, or by passing chlorine into a boiling mixture of 1 part of sulphur and 10 parts of acetic acid. The product obtained is purified by fractional distillation. Chloracetic acid melts at 63°, boils at 185°–187°, and is readily soluble in water. The acid produces painful blisters on the skin, and its vapor attacks the eyes causing tears. The halogen atom which the acid contains, can be replaced by other atoms or groups. Aminoacetic acid is prepared from the acid and ammonia: —

$$CH_2Cl.COOH + 3NH_3 = CH_2NH_2.COONH_4 + NH_4Cl$$

and hydroxyacetic acid by the action of water: —

$$CH_2Cl.COOH + HOH = CH_2OH.COOH + HCl$$

Chloracetic acid is prepared commercially for use in the synthesis of indigo, which is manufactured on the large scale.

230. Dichloracetic Acid, $CHCl_2.COOH$, can be prepared by chlorinating acetic acid, but as the acid made in this way is mixed with chloracetic acid, it is usually prepared by boiling chloral hydrate (**267**) with an aqueous solution of potassium cyanide: —

$$CCl_3CH(OH)_2 + KCN = CHCl_2.COOH + KCl + HCN$$

The acid melts at $-4°$ and boils at 189°–191°.

231. Trichloracetic Acid, $CCl_3.COOH$, is most conveniently prepared by oxidizing chloral or chloral hydrate with fuming nitric acid: —

$$CCl_3.CHO + O = CCl_3.COOH$$

The acid melts at 55° and boils at 195°. The decomposition which it undergoes when boiled with water has already been noted (**228**).

232. *α*-Brompropionic Acid, $CH_3.CHBr.COOH$, is prepared by brominating propionic acid in the presence of phosphorus.

The reactions involved have been discussed (**227**). The acid melts at 25° and boils at 205.5°. It is readily converted into lactic acid (**238**) when heated with water or a solution of an alkali: —

$$CH_3.CHBr.COOH + KOH = CH_3.CHOH.COOH + KBr$$

233. **β-Iodopropionic Acid** can be made from acrylic acid and hydriodic acid, —

$$CH_2{:}CH.COOH + HI = CH_2I.CH_2.COOH$$

but it is usually prepared by treating glyceric acid, $CH_2OH.$-$CHOH.COOH$, with hydriodic acid (phosphorus, iodine, and water): —

$$CH_2OH.CHOH.COOH + 3HI = CH_2I.CH_2.COOH + I_2 + 2H_2O$$

The reaction is analogous to that by which isopropyl iodide is prepared from glycerol.

234. **α,β-Dibrompropionic Acid**, $CH_2Br.CHBr.COOH$, can be prepared from allyl alcohol by the reactions indicated by the following formulas: —

$$CH_2{:}CH.CH_2OH \xrightarrow{Br_2} CH_2Br.CHBr.CH_2OH \xrightarrow{O} CH_2Br.CHBr.COOH$$

or by the action of phosphorus pentabromide on glyceric acid: —

$$CH_2OH.CHOH.COOH \xrightarrow{PBr_5} CH_2Br.CHBr.COOH$$

Halogen substitution-products of the unsaturated monobasic acids, and of the unsaturated and saturated polybasic acids are known. They form an interesting group of compounds, but it would lead too far to consider them here. A few will be referred to in the discussion of other compounds.

Monobasic Hydroxy-acids

235. The hydroxy-acids, or, as they used to be called, the oxy-acids, are substitution-products of the acids which contain hydroxyl groups. They may be considered, also, as derived from the alcohols by the replacement of one or more hydrogen atoms by carboxyl groups. The methods used in their preparation are based on this view of their structure. They may be prepared by introducing hydroxyl groups into acids, the methods employed being similar to those used in the synthesis of alcohols; or by introducing the carboxyl group into alcohols, the methods used in this case being similar to those applied in the preparation of acids. The more important of these methods are well illustrated by various syntheses of α-hydroxypropionic acid (lactic acid), which can be prepared by the following methods: —

1. By the action of water on a halogen-substituted acid: —

$$CH_3.CHBr.COOH + HOH = CH_3.CHOH.COOH + HBr$$

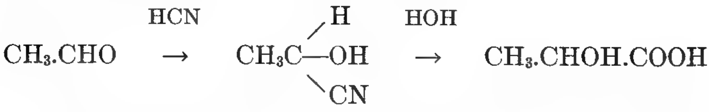
2. By the action of nitrous acid on an amino-acid: —

$$CH_3.CHNH_2.COOH + HNO_2 = CH_3.CHOH.COOH + N_2 + H_2O$$

3. By the limited oxidation of a polyatomic alcohol which contains a primary alcohol group: —

$$CH_3.CHOH.CH_2OH + 3O = CH_3.CHOH.COOH + H_2O$$

4. By the hydrolysis of the addition-products of aldehydes and ketones with hydrocyanic acid: —



$$CH_3.CHO \xrightarrow{HCN} CH_3C\begin{array}{l} \diagup H \\ —OH \\ \diagdown CN \end{array} \xrightarrow{HOH} CH_3.CHOH.COOH$$

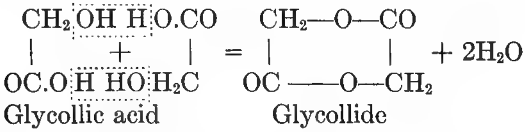
5. By the reduction of compounds which contain, in addition to a carboxyl group, a carbonyl group: —

$$CH_3.CO.COOH + 2H = CH_3.CHOH.COOH$$

The reactions of the hydroxy-acids are, in general, those of both alcohols and acids. For example, they form salts and esters; they react with the halides of phosphorus, and the hydroxyl groups are replaced by halogen; the hydrogen of both the alcoholic and acidic hydroxyl groups may be replaced by sodium; they form ethers by the replacement of the hydrogen of the alcoholic group by alkyl radicals; and so forth.

The hydroxy-acids decompose with loss of water with greater or less ease. The readiness with which the decomposition takes place, and the nature of the compound formed, are determined by the relative positions of the hydroxyl and carboxyl groups.

236. The α-hydroxy-acids are decomposed when heated. Glycollic acid, $CH_2OH.COOH$, for example, yields glycollide: —

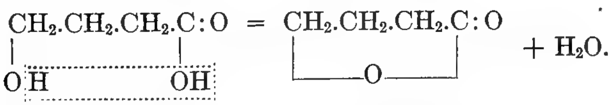


Two molecules of acid react with each other, and water is formed as the result of the interaction of the alcoholic hydroxyl group of one with the acidic hydroxyl group of the other. The resulting compound is, therefore, an ester. This is shown by the fact that the substances formed in this way from α-hydroxy-acids are readily hydrolyzed when heated with water or a solution of an alkali, and the corresponding acid is reformed.

β-Hydroxy-acids readily lose water when heated alone or in the presence of a dehydrating agent, and form unsaturated acids. In this way acrylic acid is formed from β-hydroxypropionic acid: —

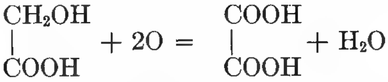
$$CH_2OH.CH_2.COOH = CH_2{:}CH.COOH + H_2.O$$

γ-Hydroxy acids and δ-hydroxy acids lose water with the greatest ease and form *lactones*. Some of these acids are so unstable that when they are liberated from their salts they pass spontaneously by loss of water into lactones. The lactones are inner esters formed as the result of the interaction of the alcoholic and acidic hydroxyl groups which the hydroxy-acids contain: —



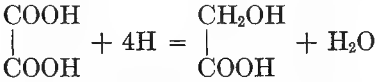
Most lactones are hydrolyzed when heated with water; the equation last given is that of a reversible reaction. A few typical oxy-acids will be considered in some detail.

237. Glycollic Acid, $CH_2OH.COOH$, which is hydroxyacetic acid, occurs in unripe grapes. It is a crystalline solid, which melts at 80°, and is readily soluble in water. It is formed, along with other substances, as the result of the oxidation of alcohol and glycol by nitric acid, and of various sugars by silver oxide. Glycollic acid is oxidized by nitric acid to oxalic acid: —



$$\begin{array}{l}CH_2OH\\ |\\ COOH\end{array} + 2O = \begin{array}{l}COOH\\ |\\ COOH\end{array} + H_2O$$

Oxalic acid on reduction with sodium amalgam yields glycollic acid: —



$$\begin{array}{l}COOH\\ |\\ COOH\end{array} + 4H = \begin{array}{l}CH_2OH\\ |\\ COOH\end{array} + H_2O$$

238. Lactic Acid, $CH_3.CHOH.COOH$, α-hydroxypropionic acid, exists in three forms, two of which are optically active. The acid contains an asymmetric carbon atom and its optical activity is traced to this cause as in the case of amyl alcohol, which has been considered at some length (**63**).

Inactive lactic acid results when lactic acid is prepared by the synthetic methods which have been mentioned (**235**). The inactive acid may be separated into its constituents by the use of certain general methods which have been found applicable in such cases. While the salts of the dextro and levo forms of active acids with metallic elements have the same solubility, and can not, therefore, be separated by crystallization, the salts formed from these acids and certain organic bases which are optically active differ in solubility. By the fractional crystallization of the strychnine salt of inactive lactic acid, two salts can be separated. The acids obtained from these differ in their action on polarized light; one is dextro-rotatory, and the other levo-rotatory.

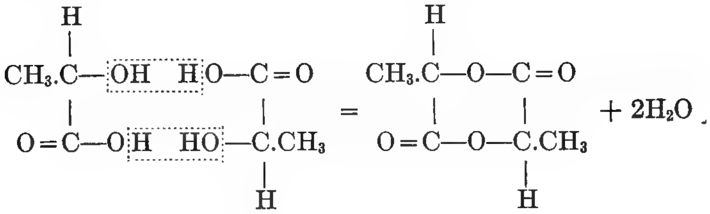
An active form of an acid may be obtained from the inactive variety by subjecting it to the action of certain bacteria, which destroy one form of the acid more rapidly than the other. In the case of lactic acid the dextro form may be obtained by the action of the mould called *penicillium glaucum* on inactive ammonium lactate. When lactic acid is made by the fermentation of milk sugar, cane sugar, or glucose, the acid formed is determined by the bacteria used. Under the influence of *micrococcus acidi paralactici* the dextro acid is obtained; with *bacillus acidi laevolactici* the levo variety is formed.

239. ***i*-Lactic Acid** was discovered in 1780 by Scheele, who isolated it from sour milk. The acid is formed as the result of the action of certain bacteria which are present in the air on the sugar which milk contains. It is found in other products which have undergone fermentation, such as "sauerkraut" and silage, which is prepared by storing grass, clover, and other cattle food under pressure. Lactic acid is present in the stomach, intestines, and muscles. It may be prepared by the application of the reactions which have been mentioned (**235**), but the methods usually employed involve the preparation of the acid from cane sugar or glucose. In one of these methods the sugar is first converted into glucose by the action of an acid. After neutralization, sour milk, decaying cheese, and calcium carbonate are added, and the mixture kept for a number of days at 40°, when fermentation takes place. The bacteria which bring about the change are present in the cheese. The milk which is added facilitates the change, as it furnishes the food which the bacteria need in their growth. The calcium carbonate is added to the mixture to keep the solution neutral, as fermentation stops when the solution contains more than one per cent of acid. The fermentation must not be allowed to continue for too long a time for, as has already been mentioned (**93**), the lactic acid produced is converted by a second fermentation into butyric acid. Calcium lactate, which is formed, is purified by crystallization, and finally decomposed by sulphuric acid, when an aqueous solution of pure lactic acid is obtained.

Lactic acid is also formed when cane sugar or glucose is boiled with a solution of sodium hydroxide. The acid may be separated from the mixture by converting it into its calcium or zinc salt. These are purified by crystallization and the acid is obtained by treating the calcium salt with sulphuric acid, or the zinc salt with hydrogen sulphide. The reaction furnishes a convenient laboratory method of preparing the acid.

240. Lactic acid, as ordinarily obtained, is a thick, colorless, odorless, hygroscopic liquid, which has the specific gravity $1.24\frac{20^\circ}{4^\circ}$.

It is miscible with water and alcohol, and is slightly soluble in ether. It decomposes when heated, but when distilled under a pressure of 1 mm. it is obtained as a liquid, which solidifies in a freezing mixture to crystals which melt at 18°. At 150° lactic acid loses water and lactide (m. p. 124°, b. p. 255°) is formed: —



$$\begin{array}{ccccccc}
\mathrm{H} & & & & \mathrm{H} & & \\
| & & & & | & & \\
\mathrm{CH_3.C—} & \boxed{\mathrm{OH\quad H}}\,\mathrm{O—C=O} & & & \mathrm{CH_3.C—O—C=O} & & \\
| & \qquad\qquad | & & = & |\qquad\quad | & & +\ 2\mathrm{H_2O} \\
\mathrm{O=C—O} & \boxed{\mathrm{H\quad HO}}\,\mathrm{—C.CH_3} & & & \mathrm{O=C—O—C.CH_3} & & \\
 & \qquad\qquad | & & & \qquad\quad | & & \\
 & \qquad\qquad \mathrm{H} & & & \qquad\quad \mathrm{H} & &
\end{array}$$

Lactide is an ester formed by the interaction of the alcoholic hydroxyl groups with the acidic hydroxyl groups. When boiled with water it is hydrolyzed, and lactic acid is formed. When lactic acid is heated with an aqueous solution of sulphuric acid, acetaldehyde and formic acid are produced: —

$$\mathrm{CH_3.CHOH.COOH = CH_3CHO + HCOOH}$$

Lactic acid is prepared by fermentation on the industrial scale. It is used in dyeing and calico printing. Antimony lactate finds application as a mordant.

241. The *structure of lactic acid* is arrived at from a study of its reactions and the methods by which it may be formed. The presence of two hydroxyl groups is shown by the fact that of the six hydrogen atoms which the acid contains, *two* can be replaced by sodium. That but one of these hydroxyl groups is acidic follows from the composition of the salts of the acid. When sodium lactate is formed by neutralizing the acid with sodium hydroxide, but *one* of the six hydrogen atoms is replaced by the metallic atom. When lactic acid is heated with hydriodic acid to a high temperature, propionic acid is formed: —

$$\mathrm{CH_3.CHOH.COOH + 2HI = CH_3.CH_2.COOH + I_2 + H_2O}$$

The reaction is analogous to that by which alcohols are reduced to hydrocarbons. In the case of lactic acid, it shows that the compound is a hydroxyl derivative of propionic acid. The fact that the hydroxyl group occupies the α-position is shown by the synthesis of lactic acid from α-brompropionic acid: —

$$CH_3.CHBr.COOH + HOH = CH_3.CHOH.COOH + HBr$$

242. ***d*-Lactic Acid** was originally called sarcolactic acid, on account of the fact that it was isolated from flesh. It is found under certain conditions in the blood and in urine, and is a characteristic constituent of muscle. It is present in "beef extract," and can be conveniently obtained from this source. It can be prepared from synthetic *i*-lactic acid by the methods which have been described (**238**). The salts of the dextro-rotatory acid differ in solubility, content of water of crystallization, and in physical properties from those of the inactive acid. They are levo-rotatory. When the acid is heated it loses its optical activity and *i*-lactic acid is formed. In general, when an optically active substance is heated it is converted into the inactive variety.

The chemical properties of *d*-lactic acid are identical with those of the inactive acid. Both acids yield the same compounds when they enter into reactions with other substances. The proofs of the structure of *i*-lactic acid which have been given apply in the case of *d*-lactic acid. The isomerism is to be attributed, therefore, to the space relations of the atoms. The same statements in regard to structure hold true in the case of *l*-lactic acid.

243. ***l*-Lactic Acid** may be obtained by the fermentation of sugar with *bacillus acidi laevolactici*, or from the salt obtained as the result of the fractional crystallization of the strychnine salt of *i*-lactic acid. It differs in properties from *d*-lactic acid only in its action on polarized light. The metallic salts of *l*-lactic acid can be distinguished from those of the *d*-acid only by examining their rotatory power. In most cases the chemical properties and physical properties of two optically active isomers are identical, except in their effect on polarized light.

244. Hydracrylic Acid, $CH_2OH.CH_2.COOH$, β-hydroxypropionic acid, is isomeric with lactic acid. It can be prepared by heating β-iodopropionic acid with water: —

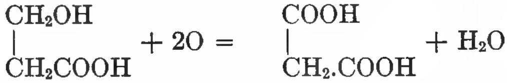
$$CH_2I.CH_2.COOH + HOH = CH_2OH.CH_2.COOH + HI$$

Other methods of synthesis which are suggested by its structure may be used.

The acid is a thick sour liquid which can not be distilled without decomposition. When heated alone, or in the presence of a dehydrating agent, it readily loses water and acrylic acid is formed: —

$$CH_2OH.CH_2.COOH = CH_2{:}CH.COOH + H_2O$$

The acid derives its name from its relation to acrylic acid. Hydracrylic acid is converted on oxidation into malonic acid: —



$$\begin{array}{l} CH_2OH \\ | \\ CH_2COOH \end{array} + 2O = \begin{array}{l} COOH \\ | \\ CH_2.COOH \end{array} + H_2O$$

This reaction, in which a carboxyl group is formed, is strong evidence that hydracrylic acid contains a primary alcoholic group.

245. Glyceric Acid, $CH_2OH.CHOH.COOH$, is an example of a dihydroxy-acid. Its name indicates its relation to glycerol from which it is prepared by careful oxidation: —

$$CH_2OH.CHOH.CH_2OH + 2O = CH_2OH.CHOH.COOH + H_2O$$

The formation of the acid from α,β-dibrompropionic acid furnishes evidence of its structure: —

$$CH_2Br.CHBr.COOH + 2AgOH = CH_2OH.CHOH.COOH + 2AgBr$$

Glyceric acid is a thick, syrupy liquid, which is miscible in all proportions with alcohol and with water. According to the structure assigned to it, the acid contains an asymmetric carbon atom. Glyceric acid does not affect polarized light, but a solution of its ammonium salt is rendered optically active by *penicillium glaucum*. A thorough investigation of the subject would, no doubt, lead to results similar to those obtained in the case of lactic acid.

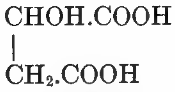
246. The polyatomic alcohols yield monobasic acids on careful oxidation. Thus from erythritol, $CH_2OH.CHOH.CHOH.CH_2OH$, erythric acid, $CH_2OH.CHOH.CHOH.COOH$, is obtained. The pentatomic alcohols give tetrahydroxy-monobasic acids. The acids derived from the hexatomic alcohols are of importance on account of their relation to the sugars. It will be recalled that a number of alcohols of the formula $CH_2OH.(CHOH)_4CH_2OH$ exist. As a molecule of this structure contains four asymmetric carbon atoms the number of possible stereoisomers which have this formula is great. There are three mannonic acids corresponding to the *dextro*, the *levo*, and the *inactive* varieties of mannitol. There are acids isomeric with mannonic acid which bear a similar relation to the other hexatomic alcohols. Three *gluconic*, three *gulonic*, and three *galactonic* acids are known. The constitution of all these acids is represented by the formula $CH_2OH(CHOH)_4COOH$.

Dibasic Hydroxy-Acids

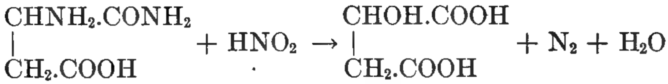
247. Tartronic Acid, $CHOH(COOH)_2$, can be prepared from malonic acid, of which it is a hydroxyl derivative, by the general method used to replace a hydrogen atom by a hydroxyl group. When malonic acid is treated with bromine, brommalonic acid is formed, which is converted into tartronic acid when boiled with silver oxide and water: —

$$CH_2(COOH)_2 \xrightarrow{Br} CHBr(COOH)_2 \xrightarrow{AgOH} CHOH(COOH)_2$$

The acid crystallizes from water and melts at 187°.

248. Malic Acid,  $\begin{array}{l} CHOH.COOH \\ | \\ CH_2.COOH \end{array}$, is a hydroxyl derivative of succinic acid. It was first described by Scheele in 1785, who called it malic acid, as he isolated it from unripe apples. The acid is widely distributed in the vegetable kingdom, and plays an important part in the growth of plants. It occurs in apples, cherries, gooseberries, raspberries, strawberries, currants, and other acidulous fruits. It is also found in the roots of marshmallow and licorice; in the leaves and stems of hemp, lettuce, and tobacco; in the seeds of caraway, parsley, flax, and pepper; in carrots, potatoes, pineapples, and grapes; and in many other vegetable substances. It is most readily prepared from unripe berries of the mountain ash. The berries are pressed under water, and the aqueous solution, which contains the acid, is neutralized with calcium hydroxide. On evaporation, the calcium salt of malic acid is obtained. The acid is isolated by adding to a solution of this salt the amount of sulphuric acid required to precipitate the calcium.

Malic acid is a solid, which is very soluble in water and crystallizes with difficulty. It melts at 100°. It may be prepared in a number of ways, which are examples of the general methods already emphasized. Two of these may be mentioned. Malic acid is formed when asparagine (**277**) is treated with nitrous acid: —

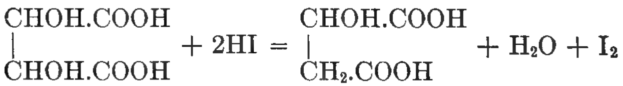


$$\begin{array}{l}\mathrm{CHNH_2.CONH_2}\\ |\\ \mathrm{CH_2.COOH}\end{array} + \mathrm{HNO_2} \rightarrow \begin{array}{l}\mathrm{CHOH.COOH}\\ |\\ \mathrm{CH_2.COOH}\end{array} + \mathrm{N_2} + \mathrm{H_2O}$$

Asparagine is derived from succinic acid by replacing one hydrogen atom and one hydroxyl group by amido groups. The compound occurs in nature in asparagus and in many other plants. The reaction by which it is converted into malic acid, is similar to those in which methyl alcohol and acetic acid are formed from methylamine and acetamide, respectively: —

$$\mathrm{CH_3NH_2 + HNO_2 = CH_3OH + N_2 + H_2O}$$
$$\mathrm{CH_3CONH_2 + HNO_2 = CH_3COOH + N_2 + H_2O}$$

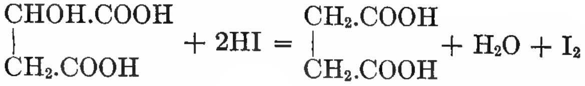
Malic acid is formed as the result of the partial reduction of tartaric acid by hydriodic acid: —



$$\begin{array}{l}\mathrm{CHOH.COOH}\\ |\\ \mathrm{CHOH.COOH}\end{array} + 2\mathrm{HI} = \begin{array}{l}\mathrm{CHOH.COOH}\\ |\\ \mathrm{CH_2.COOH}\end{array} + \mathrm{H_2O} + \mathrm{I_2}$$

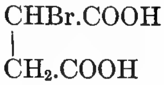
The removal of oxygen from alcohols, which consists in the reduction of a hydroxyl group to hydrogen, is effected by heating them with hydriodic acid. This reaction has been frequently mentioned. It is of importance on account of its wide application.

249. The structure of malic acid is deduced from its various syntheses and from its reactions. When heated with hydriodic acid, succinic acid is formed: —



$$\begin{array}{l}\mathrm{CHOH.COOH}\\ |\\ \mathrm{CH_2.COOH}\end{array} + 2\mathrm{HI} = \begin{array}{l}\mathrm{CH_2.COOH}\\ |\\ \mathrm{CH_2.COOH}\end{array} + \mathrm{H_2O} + \mathrm{I_2}$$

Hydrobromic acid converts malic acid into bromosuccinic acid:

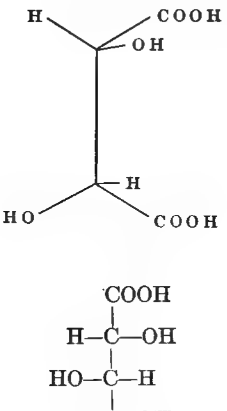


$$\begin{array}{l}\mathrm{CHBr.COOH}\\ |\\ \mathrm{CH_2.COOH}\end{array}$$

The malic acid obtained from fruits is optically active. Its aqueous solutions exhibit a behavior toward polarized light which is unusual. In concentrated solutions the acid is dextro-rotatory; as the liquid is diluted the extent of rotation decreases until it becomes zero, when, upon further dilution, the solution becomes levo-rotatory. The explanation which has been offered of this phenomenon, is that the molecule of malic acid rotates the plane of polarization to the right, but that the ion formed from it when dissolved in water is levo-rotatory. As the dilution of the solution increases the extent of ionization increases, and, consequently, the angle of rotation changes and finally becomes negative.

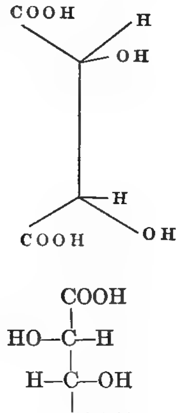
250. Dihydroxysuccinic Acids, $\begin{array}{l}\mathrm{CHOH.COOH}\\ |\\ \mathrm{CHOH.COOH}\end{array}$. — Four dihydroxysuccinic acids of this formula are known; two are active and two are inactive. The compounds described up to this point that contain asymmetric carbon atoms exist in three forms, only one of which is inactive. The existence of a second inactive form in the case of dihydroxysuccinic acid is readily explained. This acid contains two asymmetric carbon atoms, and each has an effect on the optical activity of the molecule. If the two asymmetric groupings of the atoms turn the plane of polarization to the right, the acid is dextro-rotatory; if to the left, the acid is levo-rotatory. A combination of these two forms produces an inactive variety. There is, however, another possible arrangement. One of the asymmetric groupings in the molecule may be dextro-rotatory and the other levo-rotatory. In this case one part of the molecule neutralizes the effect of the other and an inactive substance results.

The active forms of dihydroxysuccinic acid are named dextro-tartaric acid and levo-tartaric acid. The former occurs widely distributed in nature, and is usually called tartaric acid, the prefix being omitted. The inactive acid which is a mixture of dextro- and levo-tartaric acid, is racemic acid. The form which is rendered inactive by internal compensation within the molecule is mesotartaric acid or inactive tartaric acid. The relations indicated are illustrated by the following figures which represent the stereochemical formulas of d-, l-, and mesotartaric acid. Racemic acid is a mixture of the two active forms.



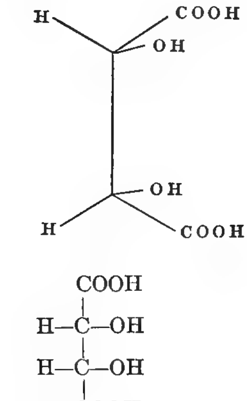
$$\begin{array}{c} COOH \\ | \\ H-C-OH \\ | \\ HO-C-H \\ | \\ COOH \end{array}$$

d–Tartaric Acid



$$\begin{array}{c} COOH \\ | \\ HO-C-H \\ | \\ H-C-OH \\ | \\ COOH \end{array}$$

l–Tartaric Acid



$$\begin{array}{c} COOH \\ | \\ H-C-OH \\ | \\ H-C-OH \\ | \\ COOH \end{array}$$

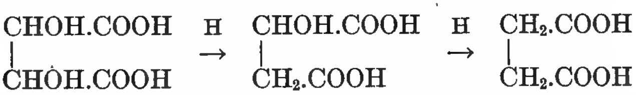
Mesotartaric Acid

There is a marked difference between the two inactive forms. Racemic acid may be separated into *d*- and *l*-tartaric acid by the methods which have been described under *i*-lactic acid. Mesotartaric acid, not being a mixture of different kinds of molecules, can not be so separated. It is changed into the active form of tartaric acid only by the application of heat, when the molecule undergoes decomposition and a new arrangement of atoms is brought about.

The term *racemic* is used as a general term in describing stereo-isomers to indicate that an inactive substance consists of a mixture of the dextro- and levo-rotatory forms. Thus, the acid which has been called inactive malic acid is said to be the racemic form of malic acid.

251. *d*-**Tartaric Acid** is widely distributed in nature in the free condition and in the form of its potassium and calcium salts. It occurs abundantly in grapes as acid potassium tartrate, which is the source of the acid of commerce. Tartaric acid crystallizes in transparent monoclinic prisms, which are readily soluble in water; it melts at 168°–170° and is dextro-rotatory. When gently heated, the acid becomes electrified, the opposite ends of the crystals assuming opposite polarity. Above its melting-point it first loses water and forms a number of different anhydrides. As the temperature is raised it turns brown, and a mass is produced which has the odor of burnt sugar. At a still higher temperature, charring takes place; from the product of decomposition pyroracemic (**261**) and pyrotartaric (methyl succinic) acids have been isolated. When tartaric acid is boiled with water or hydrochloric acid, it is partly converted into racemic acid. When an aqueous solution of the acid is heated in a sealed tube at 175°, the conversion into racemic acid is almost complete.

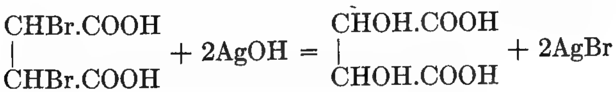
The reactions and syntheses of tartaric acid lead to the structure which has been assigned to it. When heated with hydriodic acid it is reduced to malic and to succinic acids: —



$$\begin{array}{l}\text{CHOH.COOH}\\ |\\ \text{CHOH.COOH}\end{array} \xrightarrow{\text{H}} \begin{array}{l}\text{CHOH.COOH}\\ |\\ \text{CH}_2\text{.COOH}\end{array} \xrightarrow{\text{H}} \begin{array}{l}\text{CH}_2\text{.COOH}\\ |\\ \text{CH}_2\text{.COOH}\end{array}$$

When tartaric acid is heated with alcohol in the presence of hydrogen chloride, two hydrogen atoms are replaced by two ethyl groups, and diethyl tartrate is formed. This reaction shows that the acid contains two carboxyl groups. When diethyl tartrate is heated with acetic anhydride, two acetyl groups are introduced. The ester, therefore, contains two alcoholic hydroxyl groups.

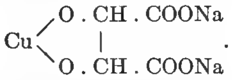
When dibromsuccinic acid is heated with silver oxide and water, racemic acid is formed: —



$$\begin{array}{l}\text{CHBr.COOH}\\ |\\ \text{CHBr.COOH}\end{array} + 2\text{AgOH} = \begin{array}{l}\text{CHOH.COOH}\\ |\\ \text{CHOH.COOH}\end{array} + 2\text{AgBr}$$

d-Tartaric and *l*-tartaric acid can be obtained in a number of ways from the acid thus synthesized.

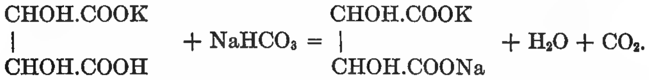
252. The accumulation of negative groups in tartaric acid brings about the development of weakly acidic properties in the alcoholic hydroxyl groups which it contains. Sodium hydroxide does not precipitate the hydroxides of copper and of certain other metals in the presence of potassium or sodium tartrate. A quantitative study of the reaction has shown that one molecule of sodium tartrate reacts with one molecule of copper hydroxide. The structure of the salt formed is represented by the formula: —



It has been obtained in the form of crystals, which contain two molecules of water of crystallization. The color of the solution formed by adding copper sulphate to an alkaline solution of sodium tartrate is deep blue; it resembles closely that produced when an excess of ammonia is added to a cupric salt. When a solution of this blue salt of tartaric acid is subjected to electrolysis, the sodium travels to the cathode and the copper to the anode. The region around the cathode loses its color and, finally, contains no copper, and that around the anode becomes richer in copper. These facts indicate that the copper is contained in the negative ion of the salt, — a conclusion which is in accord with the structure assigned to it. The solution formed by adding copper sulphate to an alkaline solution of a tartrate is called *Fehling's solution*. It is a mild oxidizing agent, and is much used as a reagent in the study of carbohydrates.

253. Tartaric acid and its salts have a number of commercial applications. The acid is used in dyeing, and in one form of baking powder. *Acid potassium tartrate*, $C_4H_4O_6.KH$, occurs in many fruits. It is obtained commercially from *argol*, which is the deposit formed in wine casks during the fermentation of grape-juice. The salt is but slightly soluble in water, and its solubility is diminished in the presence of alcohol. As fermentation proceeds it is precipitated, along with tannin, coloring matters, and albuminous substances. The pure salt is obtained from the mixture by boiling it with water and bone-black, and evaporating the clear solution after filtering. Acid potassium tartrate is commonly called *cream of tartar*.

Cream of tartar is used in large quantities in the manufacture of the so-called tartrate *baking-powders*. These consist of a mixture of cream of tartar, sodium bicarbonate, and starch. When water is added to baking-powder, the acid tartrate and bicarbonate react, and carbon dioxide is formed: —

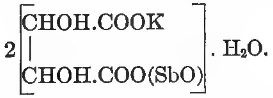


$$\begin{array}{l}\mathrm{CHOH.COOK}\\ |\\ \mathrm{CHOH.COOH}\end{array} + \mathrm{NaHCO_3} = \begin{array}{l}\mathrm{CHOH.COOK}\\ |\\ \mathrm{CHOH.COONa}\end{array} + \mathrm{H_2O} + \mathrm{CO_2}.$$

Starch is added to baking-powder for two reasons: it covers the particles of the salts present, and thus protects them from moisture and from interacting when the powder is stored, and it serves as a diluent. It is customary to make baking-powders which liberate about 13 per cent of their weight of carbon dioxide when treated with water. As a mixture of equal molecular quantities of cream of tartar and sodium bicarbonate produces more than this amount of carbon dioxide, an inert substance must be added to reduce that formed to the percentage desired. Baking-powders are also made by mixing sodium bicarbonate with primary calcium phosphate or with aluminium sulphate or alum. The presence of a tartrate in a baking-powder can be determined by applying the test for tartaric acid which is described below.

Rochelle salt is the name given to sodium potassium tartrate, $C_4H_4O_6KNa.4H_2O$. It can be obtained readily in pure condition, as it crystallizes well. It is used in the preparation of Fehling's solution, and in medicine as a diuretic and a purgative. Seidlitz powders contain (1) Rochelle salt and sodium bicarbonate and (2) tartaric acid. When solutions of the two powders are mixed there is a vigorous evolution of carbon dioxide.

Tartar emetic is the potassium antimonyl salt of tartaric acid: —



$$2\left[\begin{array}{l}\mathrm{CHOH.COOK}\\ |\\ \mathrm{CHOH.COO(SbO)}\end{array}\right].\,\mathrm{H_2O}.$$

It was formerly much used as an emetic, as it has an irritating effect on the alimentary canal which causes vomiting. It is used as a mordant in dyeing.

254. Tests for Tartaric Acid. — When a solution of calcium chloride is added to a neutral solution of a tartrate, calcium tartrate $C_4H_4O_6Ca.4H_2O$, is precipitated. The latter is readily soluble in potassium hydroxide, but is precipitated in a gelatinous form on heating the solution to boiling. Ammonium salts should be excluded in making the test, as they interfere with the precipitation of calcium tartrate. A positive test for a tartrate should be confirmed by heating the substance with an ammoniacal solution of silver nitrate, when, if a tartrate is present, the silver salt will be reduced and a mirror of the metal will be deposited. When tartaric acid or a tartrate is heated alone, the substance chars and an odor similar to that of burnt sugar is produced. When heated with concentrated sulphuric acid, carbon is deposited, and sulphur dioxide, carbon monoxide, and carbon dioxide are evolved.

255. Racemic Acid occurs in nature free, or in the form of salts, along with tartaric acid and tartrates. Acid potassium racemate is much more soluble than acid potassium tartrate, and is obtained as a by-product in the preparation of the latter from argol. Racemic acid is formed when tartaric acid is heated with water or with solutions of hydrochloric acid or sodium hydroxide. It is a product of the oxidation of dulcitol, mannitol, cane sugar, and similar substances. It can be synthesized, along with mesotartaric acid, by heating a solution of dibromsuccinic acid with silver oxide. The acid and its salts differ markedly in physical properties from tartaric acid and the tartrates. Racemic acid melts at 205°–206° and forms crystals which contain one molecule of water. Tartaric acid melts at 168°–170° and is anhydrous.

Racemic acid is of considerable historical interest as it was the first inactive substance to be resolved into optically active compounds. The remarkable discovery was made by Pasteur in 1848 in an investigation of the crystalline structure of the salts of racemic acid. It was found that two kinds of crystals, which differed slightly in the relative position of the faces they contained, were formed when a solution of the sodium ammonium salt of racemic acid was allowed to crystallize spontaneously. The relation in form which the two kinds of crystals bear to each other, is that of an object and its reflection in a mirror. Pasteur separated the two kinds of crystals and examined the solutions of each in polarized light. He found that one solution was dextro-rotatory and the other was levo-rotatory. From the two salts two acids were isolated; one was ordinary *d*-tartaric acid, the other a new acid which was levo-rotatory. When equal weights of the two acids were mixed and recrystallized, inactive racemic acid was obtained.

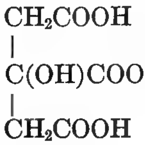
It was shown later that if the crystals of sodium ammonium racemate are deposited from solution at a temperature above 28°, crystals of but one kind are obtained. These differ in form and content of water of crystallization from the crystals of the corresponding salts of *d*-tartaric and *l*-tartaric acids, which are obtained when the temperature is below 28°.

Pasteur devised in his investigation other important methods of breaking down the racemic form of acids into their optical isomers. He showed that the salts of the latter with optically active bases possess different solubilities, and that this fact could be utilized in separating these acids into their constituents.

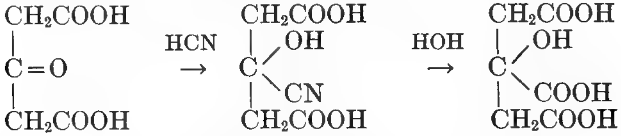
The third method devised by Pasteur depends on the action of certain moulds and bacteria on racemic compounds. One of the active substances is more rapidly destroyed than the other. When the mould *penicillium glaucum* develops in a dilute solution of racemic acid, the dextro-rotatory acid is destroyed and *l*-tartaric acid is obtained.

256. ***l*-Tartaric Acid** can be prepared from racemic acid by the methods which have been mentioned in the last section. The acid has the same physical properties as tartaric acid except its action on polarized light. The extent to which the plane of polarization is rotated is the same in both cases, but the direction of rotation is different. The salts of the two acids are, in general, alike in solubility, content of water of crystallization, and so forth. It will be recalled, however, that there is a slight difference in the form of the crystals of sodium ammonium salts of *d*- and *l*-tartaric acid, and that the difference furnishes a method of separating these optical isomers.

257. Mesotartaric Acid is formed along with racemic acid when tartaric acid is heated with water at 165° for two days, or when a solution of sodium tartrate is boiled for a number of hours with sodium hydroxide. It can be synthesized by heating dibromsuccinic acid with silver oxide and water, racemic acid being formed at the same time. Mesotartaric acid differs in physical properties from tartaric acid and racemic acid. It crystallizes with one molecule of water of crystallization. The anhydrous acid melts at 140°. The stereo-chemical relations of mesotartaric acid have already been explained (**250**).

258. Citric Acid,  $\begin{array}{l} CH_2COOH \\ | \\ C(OH)COOH.H_2O \\ | \\ CH_2COOH \end{array}$, is a monohydroxy-tri-

basic acid. The fact that it contains three carboxyl groups and one alcoholic hydroxyl group is inferred from its chemical behavior. Citric acid, like other tribasic acids, forms three potassium salts. The composition of its ethyl ester also indicates that the acid is tribasic. When the ester is treated with acetic anhydride, one hydrogen atom is replaced by an acetyl group. This reaction shows that the substance contains one alcoholic hydroxyl group. The position of this group is determined by a synthesis of citric acid from acetone-dicarbonic acid, which is, as implied in the name, acetone in which two hydrogen atoms are replaced by two carboxyl groups. The steps in the synthesis of citric acid are represented by the following formulas: —

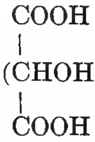


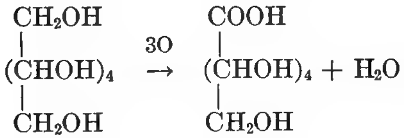
Citric acid occurs widely distributed in nature in many fruits. It is present in raspberries, gooseberries, currants, and other acidulous fruits. It is usually obtained from unripe lemons, the juice of which contains about six per cent of the free acid. In isolating the acid, the juice is neutralized at the ordinary temperature with calcium carbonate, and filtered. Tricalcium citrate dissolves readily in cold water, but is difficultly soluble in hot water. As a consequence, when the solution of the citrate obtained from the lemon juice is boiled, the calcium salt of the acid precipitates. This is separated and treated with an equivalent quantity of sulphuric acid; after the removal of calcium sulphate, citric acid is obtained by evaporation of the solution to crystallization. Citric acid is formed as the result of the fermentation of glucose by *citromycetes pfefferianus*. It is prepared on the technical scale in this way.

Citric acid crystallizes from water in rhombic prisms, which melt at 100° and contain one molecule of water of crystallization. The hydrated acid loses water at about 130°. The anhydrous acid melts at 153°.

Citric acid is used in the manufacture of lemonade and in calico-printing. A number of its salts have important applications.

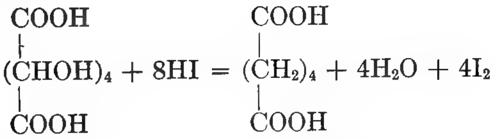
Magnesium citrate $(C_6H_5O_7)_2Mg_3.14H_2O$, is used in medicine. *Ferric ammonium citrate* $(C_6H_5O_7Fe.C_6H_5O_7(NH_4)_2H)$, is used in making "blue-print" paper (**195**). A strong solution of neutral ammonium citrate is used in the analysis of fertilizers in the separation of the different forms of phosphates which the fertilizers contain.

259. Saccharic Acid and Mucic Acid,  $\begin{array}{c} COOH \\ | \\ (CHOH)_4 \\ | \\ COOH \end{array}$, are the more important of a large number of acids which have been shown to have this formula. As the configuration represented by this formula contains four asymmetric carbon atoms, sixteen stereo-isomers are possible. The number of such isomers is 2^n, where n is the number of asymmetric carbon atoms in the molecule. *d*-Saccharic acid is formed as the result of the oxidation of glucose, cane-sugar, and milk-sugar by nitric acid. As the last two are converted into glucose by hydrolysis, *d*-saccharic acid is probably formed as the first oxidation-product of glucose. The reaction is readily understood. It will be shown later that glucose contains a primary alcohol group and an aldehyde group. In the change to saccharic acid these groups are converted into carboxyl: —



$$\begin{array}{c} CH_2OH \\ | \\ (CHOH)_4 \\ | \\ CH_2OH \end{array} \xrightarrow{3O} \begin{array}{c} COOH \\ | \\ (CHOH)_4 \\ | \\ CH_2OH \end{array} + H_2O$$

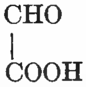
The constitution of saccharic acid is inferred from its relation to glucose, and from the fact that it is reduced by hydriodic acid to adipic acid: —



$$\begin{array}{c} COOH \\ | \\ (CHOH)_4 \\ | \\ COOH \end{array} + 8HI = \begin{array}{c} COOH \\ | \\ (CH_2)_4 \\ | \\ COOH \end{array} + 4H_2O + 4I_2$$

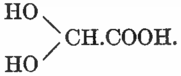
Mucic acid is formed by the oxidation of galactose and of other substances which give this sugar on hydrolysis. As galactose is a stereo-isomer of glucose, and as hydriodic acid reduces mucic acid to adipic acid, it is inferred that mucic acid is a stereoisomer of saccharic acid. The acid is best prepared by oxidizing sugar of milk with nitric acid. It is optically inactive, and can not be resolved into optically active compounds.

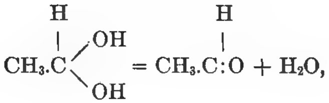
Aldehyde-acids and Ketone-acids

260. Glyoxylic Acid,  $\begin{array}{c}CHO\\|\\COOH\end{array}.H_2O$, is the simplest example of compounds which contain the groups characteristic of aldehydes and of acids. It is found in the leaves and the unripe fruits of many plants. It can be prepared by heating dibromacetic acid with water for 24 hours in a sealed tube at 135°, —

$$CHBr_2.COOH + HOH = CHO.COOH + 2HBr$$

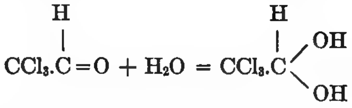
or by the partial oxidation of alcohol by nitric acid.

The acid is a crystalline substance, very soluble in water, and has the composition $CHO.COOH.H_2O$. The added water does not appear to be "water of crystallization," as the compound can not be decomposed into anhydrous glyoxylic acid and water by heat. When an attempt is made to drive the water out of the compound, complete decomposition results. The structure of the compound, as given above, is not satisfactory, as it leads to a false conception as to its behavior when heated. For this reason the structure sometimes assigned to glyoxylic acid is that represented by the formula  $\begin{array}{l}HO\diagdown\\ \quad\quad CH.COOH\\HO\diagup\end{array}$. This formula, which is that of dihydroxy-acetic acid, indicates that the compound contains two hydroxyl groups, and that it does not contain water of crystallization. If this view of the structure is correct, the compound is an exception to the general rule which has been given, — namely, that two hydroxyl groups can not be held in combination by a single carbon atom. Exceptions to this general statement are known. A consideration of the structure of compounds which contain two hydroxyl groups linked to a single carbon atom, brings out the fact that in all such compounds the carbon atom which shows this unusual power, is linked to a second carbon atom to which are united strongly negative atoms or groups. For example, whereas aldehyde is formed as the result of the elimination of water from a dihydroxyl derivative according to the equation, —



$$CH_3.\overset{\overset{H}{|}}{C}\begin{array}{l}\diagup OH\\ \diagdown OH\end{array} = CH_3.\overset{\overset{H}{|}}{C}:O + H_2O,$$

trichloraldehyde adds water, and in all probability forms a compound which contains two hydroxyl groups joined to the same carbon atom: —



$$CCl_3.\overset{H}{\overset{|}{C}}=O + H_2O = CCl_3.\overset{H}{\overset{|}{C}}\begin{matrix} / OH \\ \backslash OH \end{matrix}$$

The reaction in this case is the opposite of that with aldehyde. Other compounds which contain strongly negative groups act in a similar way. Glyoxylic acid contains the carboxyl group, which is negative, and, consequently, the stable configuration of the acid may be that in which two hydroxyl groups are present. The action of the acid when heated is best indicated, therefore, by writing its formula as $CH(OH)_2.COOH$. The reactions of glyoxylic acid with other substances are not expressed, however, by this formula. It reduces an ammoniacal solution of silver nitrate, forms addition-products with acid sodium sulphite and ammonia, and gives an oxime with hydroxylamine. These reactions, which are all characteristic of aldehydes, lead to the view that the acid contains an aldehyde group; its structure is therefore best represented by the formula $CHO.COOH.H_2O$.

261. Pyroracemic Acid, $CH_3CO.COOH$, is an example of a compound which is both an acid and a ketone. The name was given to the acid when it was first prepared by heating racemic acid. The prefix *pyro* appears in the name of many substances, such as pyrophosphoric acid, pyrotartaric acid, pyrogallic acid, and so forth. It is derived from the Greek word meaning fire, and was used in naming compounds to indicate that they were formed by the action of heat. Pyrogallic acid, for example, is formed when gallic acid is heated.

Pyroracemic acid may be prepared by methods which furnish evidence in favor of the structure assigned to it. It is formed, for example, by oxidizing lactic acid: —

$$CH_3.CHOH.COOH + O = CH_3.CO.COOH + H_2O$$

In this case the reaction is normal — a secondary alcohol group is converted into the carbonyl (CO) group, which is present in ketones. It is also formed by the reactions indicated by the following equations: —

$$CH_3.CCl_2.COOH + H_2O = CH_3.CO.COOH + 2HCl$$
$$CH_3CO.Cl + KCN = CH_3CO.CN + KCl$$
$$CH_3CO.CN + 2H_2O = CH_3CO.COOH + NH_3$$

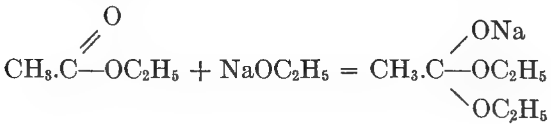
Pyroracemic acid melts at 9° and boils at 165°. It shows the reactions of both acids and ketones. It forms salts, esters, an oxime, and an addition-product with hydrocyanic acid. When heated with dilute sulphuric acid at 150°, it decomposes according to the following equation: —

$$CH_3CO.COOH = CH_3.CHO + CO_2$$

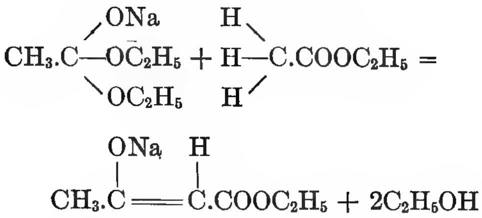
262. Acetoacetic Acid, $CH_3CO.CH_2COOH$, is so-called, because it may be considered as acetic acid in which one hydrogen atom is replaced by the acetyl group. It is known only in solution, for when an attempt is made to isolate it, decomposition takes place. It is found in the urine of persons suffering from diabetes.

263. Acetoacetic Ester: Tautomerism. — The ethyl ester of acetoacetic acid is of interest, as its study has led to a deeper insight into the nature of molecules and to a broadening of the theories of structural organic chemistry. Acetoacetic ester is also of importance from the practical point of view; by the use of appropriate reagents many compounds can be prepared from it by what is called the acetoacetic ester synthesis.

Acetoacetic ester is prepared by condensing ethyl acetate by means of sodium ethylate. Ethyl acetate containing a trace of ethyl alcohol is boiled with sodium. When the metal has dissolved, the reaction-product is treated with dilute acid, and the oil set free is dried and purified by distillation. The various steps involved in the transformation of ethyl acetate into ethyl acetoacetate, have been the subject of much discussion. The view accepted by most chemists is that given by Claisen. It is as follows: When sodium is added to ethyl acetate it first reacts with the small amount of alcohol present to form sodium ethylate and hydrogen. The addition-product of sodium ethylate and ethyl acetate which results, condenses with a second molecule of ethyl acetate: —



$$CH_3.\overset{\overset{O}{/\!\!/}}{C}—OC_2H_5 + NaOC_2H_5 = CH_3.C\begin{array}{l}\diagup ONa\\ —OC_2H_5\\ \diagdown OC_2H_5\end{array}$$



The alcohol eliminated in the second reaction is converted by the metal into sodium ethylate, which serves to bring about the condensation of more ethyl acetate. Ethyl acetoacetate is liberated when the sodium compound is treated with an acid: —

$$\begin{aligned}&CH_3C(ONa):CH.COOC_2H_5 + CH_3COOH = \\ &CH_3C(OH):CH.COOC_2H_5 + CH_3COONa.\end{aligned}$$

This explanation of the formation of ethyl acetoacetate leads to the view that it is the ester of an unsaturated hydroxy-acid. Some of its reactions are in accord with this view of its structure. On the other hand, it behaves with certain reagents as if it contained the group characteristic of ketones, and, consequently, its structure should be represented by the formula $CH_3CO.CH_2.COOC_2H_5$. A detailed study of the ester has led to the conclusion that it can exist in two forms, and that the structure of these two forms can best be represented by the formulas which have been given. It has been shown, also, that one form of the ester can change spontaneously into the other form, and that the free ester is a mixture in which the two forms are in equilibrium: —

$$CH_3C(OH):CH.COOC_2H_5 \rightleftharpoons CH_3CO.CH_2COOC_2H_5$$

The derivatives of acetoacetic esters are mixtures of substitution-products of the two forms of the ester. The relation between the amounts of each form present in any substance, varies with the nature of the groups present in the molecule; in some, the form which contains the ketone group largely predominates, while in others, the unsaturated compound is present in the larger quantity. The form which contains the hydroxyl group is designated by the word *enol;* that which contains the carboxyl group is the *keto* form.

This explanation of the structure of acetoacetic ester and its derivatives makes it necessary to recognize a kind of isomerism unlike that which aroused the attention of chemists in the early days of organic chemistry. The relation between the two dibromethanes, $CH_3.CHBr_2$ and $CH_2Br.CH_2Br$, is different from that between the two forms of acetoacetic ester. The former are stable compounds, and each has definite physical and chemical properties. The two isomeric forms of acetoacetic ester and its derivatives are less stable and change spontaneously one into the other. If we prepare one form in pure condition — and this can be done in the case of certain derivatives of the ester — it will, with greater or less rapidity, change to the other form, and, finally, a mixture results in which the two forms are in equilibrium. Isomerism of this type is called *tautomerism.* It is observed in the case of many compounds. Before it was recognized and the theory of structure was extended to include such phenomena, it was impossible to assign to many compounds structural formulas which expressed their chemical reactions.

A number of experimental methods have been discovered of following the rearrangement of one form of a tautomeric compound into the other. It has been found that a colored substance is formed when a compound which has the *enol* structure is treated with ferric chloride; the *keto* form is not affected by this reagent. If ferric chloride is added to a comparatively stable substance which has the *keto* structure no color appears; as the transformation progresses a color develops and increases in intensity until equilibrium is established. If the reagent is added to the *enol* form of the same substance, the color appears at once; it decreases in intensity as the rearrangement to the *keto* form takes place, until the equilibrium point is reached.

A second method of investigating the structure of tautomeric compounds, is that devised by Brühl, who showed that substances which contain carbon atoms linked by a double bond disperse and refract light more strongly than saturated compounds. As the *enol* form of tautomers contain doubly-linked carbon atoms, and the *keto* form does not, the rearrangement of one form into the other can be followed by examining the optical properties of the substances studied.

These methods of investigating the change of tautomers, one into the other, has lead to the discovery that the rate at which the change takes place is affected by the temperature and the nature of the liquid in which the compound is dissolved. Increase in temperature and solvents containing the hydroxyl group, such as water and alcohol, increase the rate of change. When the solvent used is a hydrocarbon or halogen derivative, the rate is greatly reduced.

The chemical properties of acetoacetic ester are those of a ketone and an ester. It contains, however, a small proportion of the tautomeric *enol* form of the compound, as a color is produced when it is treated with ferric chloride. The ester dissolves in alkalies owing to the formation of a soluble sodium salt. It is believed that the salt is formed as the result of the interaction of the alkali with that part of the ester which has the *enol* structure. As the latter is removed in this way the *keto* form undergoes rearrangement to the *enol* form in order to establish the normal equilibrium between the two forms. The change continues until, in the end, the ester dissolves completely. When an aqueous solution of the sodium salt of acetoacetic ester is treated with an acid, the salt is decomposed and the ester is precipitated.

264. Acetoacetic Ester Synthesis. — The hydrolysis of acetoacetic ester and its derivatives presents many points of interest, on account of the fact that the acid and its substitution-products, which are formed by the hydrolysis, are unstable and yield important decomposition-products. When the saponification of acetoacetic ester is effected by boiling it with a dilute aqueous solution of an acid, it is probable that alcohol and acetoacetic acid are first formed: —

$$CH_3CO.CH_2COOC_2H_5 + HOH = CH_3CO.CH_2COOH + C_2H_5OH$$

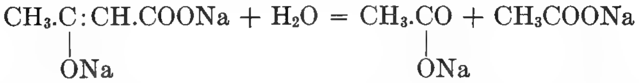
The acid is, however, unstable under these conditions, and decomposes, yielding acetone and carbon dioxide: —

$$CH_3.CO.CH_2 \vdots COOH = CH_3.CO.CH_3 + CO_2$$

When acetoacetic ester is hydrolyzed by boiling it with a strong aqueous solution of an alkali, or with an alcoholic solution of potassium hydroxide, the sodium salt of acetoacetic ester, $CH_3C(ONa):CH.COOC_2H_5$, which is first formed, is hydrolyzed, in all probability, according to the equation, —

$$CH_3C(ONa):CH.COOC_2H_5 + NaOH =$$
$$CH_3C(ONa):CH.COONa + C_2H_5OH$$

In the presence of the strong alkali, the salt undergoes decomposition as the result of the addition of water at the double bond, and two molecules of sodium acetate are formed: —



$$CH_3.\underset{\displaystyle ONa}{\underset{|}{C}}:CH.COONa + H_2O = CH_3.\underset{\displaystyle ONa}{\underset{|}{C}}O + CH_3COONa$$

The derivatives of acetoacetic ester undergo decompositions similar to those of the ester itself. As many substitution-products of acetoacetic ester can be prepared, we have, thus, a means of synthesizing substitution-products of acetone and of acetic acid.

When the sodium derivative of acetoacetic ester is warmed with an alkyl halide, the metallic atom is replaced by an alkyl group. The stable form of these substances appears to have the *keto* structure. The reaction is usually effected by treating an alcoholic solution of acetoacetic ester with the calculated quantity of sodium ethylate, which converts the ester into its sodium derivative: —

$$CH_3CO.CH_2COOC_2H_5 + C_2H_5ONa =$$
$$CH_3C(ONa):CHCOOC_2H_5 + C_2H_5OH$$

The alkyl iodide is then added and the solution boiled until the reaction is complete: —

$$CH_3.C(ONa):CHCOOC_2H_5 + CH_3I =$$
$$CH_3.CO.CH(CH_3).COOC_2H_5 + NaI$$

The resulting compound is now hydrolyzed by either of the methods which have been described. When boiled with a dilute acid or dilute aqueous potassium hydroxide, the decomposition yields, in the example given, methyl ethyl ketone and carbon dioxide: —

$$CH_3.CO.CH(CH_3)\vdots COOH = CH_3.CO.CH_2CH_3 + CO_2$$

This is an example of what is known as the ketonic hydrolysis.

When the ester is hydrolyzed by boiling with alcoholic potassium hydroxide, the salts of two acids, which in this case are acetic acid and propionic acid, are formed. This is known as the acid hydrolysis: —

$$CH_3.CO\vdots CH(CH_3).COOH + HOH = CH_3.COOH + CH_3CH_2.COOH$$

It is evident that by varying the alkyl halide used in the synthesis, a large number of ketones and acids may be prepared.

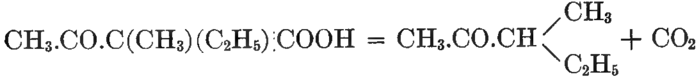
The alkyl substitution-products of acetoacetic ester, which can be prepared by the methods just described, react with sodium ethylate and form metallic derivatives: —

$$CH_3.CO.CH(CH_3).COOC_2H_5 + C_2H_5ONa = CH_3.C(ONa):C(CH_3).COOC_2H_5 + C_2H_5OH$$

These, in turn, react with alkyl halides and yield substitution-products of acetoacetic ester which contain two alkyl radicals: —

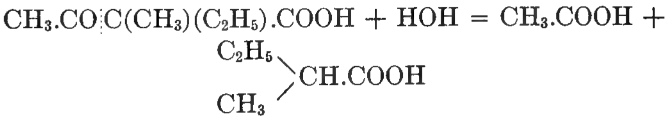
$$CH_3.C(ONa):C(CH_3).COOC_2H_5 + C_2H_5I = CH_3.CO.C(CH_3)(C_2H_5).COOC_2H_5 + NaI$$

Ketonic hydrolysis of this compound yields methyl secondary-butyl ketone: —



$$CH_3.CO.C(CH_3)(C_2H_5)\vdots COOH = CH_3.CO.CH\left\langle\begin{array}{l}CH_3\\C_2H_5\end{array}\right. + CO_2$$

Acid hydrolysis yields acetic acid and a valeric acid: —



$$CH_3.CO\vdots C(CH_3)(C_2H_5).COOH + HOH = CH_3.COOH + \left.\begin{array}{l}C_2H_5\\CH_3\end{array}\right\rangle CH.COOH$$

It will be seen from the examples given that by means of the acetoacetic ester synthesis ketones of the structure $CH_3.CO.CH_2R$ and $CH_3.CO.CHRR'$ may be prepared. R and R′ indicate radicals. Acid hydrolysis yields acids of the structure $RCH_2.COOH$ and $RR'CH.COOH$.

Acid chlorides, as well as alkyl halides, react with the sodium derivative of acetoacetic ester; as a consequence, ketones and acids which contain acyl radicals can be prepared by means of this synthesis.

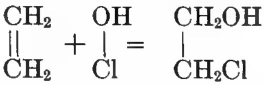
Halogen Substitution-products of Alcohols, Aldehydes, and Ketones

265. Many halogen substitution-products of the various classes of compounds which have been described, are known. Some of these are of special interest as they illustrate in their methods of preparation and reactions important principles of organic chemistry. It would lead too far to describe many of these compounds or others of a more complex structure, such as those which contain three or more characteristic groups in the molecule. A few typical compounds only will be mentioned.

266. Halogen Derivatives of Alcohols. — Substitution-products of alcohols can not be prepared, as a rule, by the action of the halogens on the alcohols. Derivatives of an aldehyde are formed when a saturated alcohol is treated, for example, with chlorine. The halogen either oxidizes the alcohol directly to an aldehyde, or forms a substitution-product which immediately decomposes into an aldehyde. Further action of the halogen results in the formation of a halogen substitution-product of an aldehyde. It is possible that the steps in the reaction in the case of ethyl alcohol may be those represented by the following equations: —

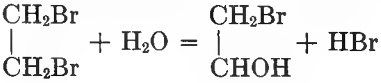
$$CH_3.CH_2OH + Cl_2 = CH_3.CHClOH + HCl$$
$$CH_3.CHClOH = CH_3.CHO + HCl$$
$$CH_3.CHO + 3Cl_2 = CCl_3.CHO + 3HCl$$

Halogen derivatives of the alcohols must, accordingly, be made by indirect methods. They are formed (1) by the action of hypochlorous acid on unsaturated hydrocarbons, —



$$\begin{array}{c}CH_2\\ \|\\ CH_2\end{array} + \begin{array}{c}OH\\ |\\ Cl\end{array} = \begin{array}{l}CH_2OH\\ |\\ CH_2Cl\end{array}$$

(2) by the partial hydrolysis of dihalogen derivatives, —



$$\begin{array}{l}CH_2Br\\ |\\ CH_2Br\end{array} + H_2O = \begin{array}{l}CH_2Br\\ |\\ CHOH\end{array} + HBr$$

(3) by the action of the halogens on unsaturated alcohols, —

$$CH_2{:}CH.CH_2OH + Cl_2 = CH_2Cl.CHCl.CH_2OH$$

and (4) by the action of the halogen hydrides on polyatomic alcohols, —

$$CH_2OH.CH_2OH.CH_2OH + 2HCl = CH_2Cl.CHOH.CH_2Cl + 2H_2O$$

In the last case, the conditions under which the reaction is brought about determine the extent to which the hydroxyl groups are replaced by halogen. For example, when glycerol is heated with dry hydrogen chloride, the chief product of the reaction has the structure $CHCl.CHOH.CH_2OH$. When the reaction takes place in a glacial acetic acid solution, two hydroxyl groups are replaced by chlorine atoms.

The chemical properties of the halogen substitution-products of the alcohol are, in general, those shown by alcohols and those shown by the alkyl halides. The presence of the negative halogen atom in the alcohol modifies to some extent the reactivity of the hydroxyl group, and likewise the presence of the latter affects the ease with which the halogen enters into reaction with other substances.

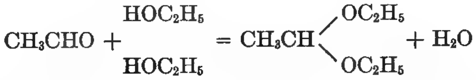
267. Halogen Derivatives of Aldehydes. — The most important of these compounds is trichloraldehyde, $CCl_3.CHO$, which is usually called *chloral*. It is formed when an aqueous solution of aldehyde is treated with chlorine, but is usually prepared by the action of the halogen on anhydrous alcohol. The reactions involved are complicated. It has already been pointed out that chlorine converts alcohol into aldehyde. A reaction may be written for the change: —

$$CH_3.CH_2OH + Cl_2 = CH_3.CHO + 2HCl$$

The aldehyde reacts with chlorine and is converted into trichloraldehyde, which, in turn, unites with water set free in a secondary reaction to form chloral hydrate. The changes are indicated by the formulas: —

$$CH_3.CHO \xrightarrow{Cl_2} CCl_3.CHO \xrightarrow{H_2O} CCl_3.CHO.H_2O$$

The fact that hydrogen chloride is formed as the result of the substitution of hydrogen by chlorine, leads to reactions other than substitution. It will be recalled that aldehydes undergo condensation with alcohols to form acetals in the presence of hydrogen chloride, which catalizes the reaction (**146**): —

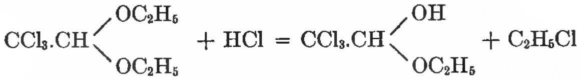


$$CH_3CHO + \begin{matrix} HOC_2H_5 \\ HOC_2H_5 \end{matrix} = CH_3CH\begin{matrix} \diagup OC_2H_5 \\ \diagdown OC_2H_5 \end{matrix} + H_2O$$

When chlorine is passed into alcohol the conditions are favorable for this reaction and acetal is formed. The latter then is converted into trichloracetal: —

$$CH_3.CH(OC_2H_5)_2 + 3Cl_2 = CCl_3.CH(OC_2H_5)_2 + 3HCl$$

In the presence of the acid some of the acetal is decomposed: —

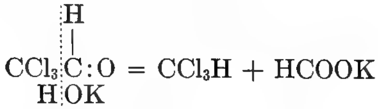


$$CCl_3.CH\begin{matrix} \diagup OC_2H_5 \\ \diagdown OC_2H_5 \end{matrix} + HCl = CCl_3.CH\begin{matrix} \diagup OH \\ \diagdown OC_2H_5 \end{matrix} + C_2H_5Cl$$

The resulting product is called chloral alcoholate, as it can be formed by the direct union of chloral and alcohol. As the consequence of all these reactions, the product finally obtained when alcohol is treated with chlorine is a mixture which contains chloral hydrate, trichloracetal, and chloral alcoholate. Chloral is set free from these compounds when the mixture is treated with concentrated sulphuric acid.

Chloral is an oily liquid, which has a penetrating odor; it boils at 97° and has the specific gravity 1.512 at $\frac{20°}{4°}$. It reacts with water with the evolution of heat, and forms chloral hydrate, a compound which crystallizes well from water and melts at 57°. Chloral hydrate is much used as a soporific. The formula usually assigned to chloral hydrate is $CCl_3.CH(OH)_2$. There is in this case the same uncertainty as to structure as in the case of glyoxylic acid (**260**). Chloral hydrate shows most of the reactions of aldehydes: it reduces an ammoniacal solution of silver nitrate, and reacts with hydroxylamine. It does not, however, decolorize Schiff's reagent (**151**). Concentrated sulphuric acid converts it into chloral.

Both chloral and chloral hydrate yield trichloracetic acid when oxidized by concentrated nitric acid, the reaction which takes place being that characteristic of aldehydes. When treated with a solution of potassium hydroxide, chloral is decomposed in the cold, and chloroform is formed: —



$$\begin{array}{l} \qquad\ \ \mathrm{H} \\ \qquad\ \ | \\ \mathrm{CCl_3\,C{:}O} = \mathrm{CCl_3H} + \mathrm{HCOOK} \\ \qquad \mathrm{H\,OK} \end{array}$$

This decomposition is a further example of a principle which has been emphasized, namely, that the accumulation of negative atoms in a molecule markedly affects the union between the carbon atoms with which the negative atoms are in combination.

268. Halogen Derivatives of Ketones. — Compounds of this class are prepared by the action of chlorine and bromine on ketones, the substitution taking place readily. It has been pointed out that the introduction of oxygen into a compound is facilitated, in general, by the presence of oxygen in the compound; alcohols, aldehydes, and ketones are much more readily oxidized than hydrocarbons. The presence of the negative atom, in some way, makes it easier to introduce a second negative atom. This is true not only in the case where the latter is oxygen, but where it is another negative atom. Chlorine and bromine react much more readily with the oxygen derivatives of the hydrocarbons than with the hydrocarbons themselves.

A number of substitution-products of acetone can be formed by the action of chlorine on acetone. The extent to which substitution takes place is determined by such conditions as the relation between the amounts of substances used, the temperature, the presence of catalytic agents, and so forth. The dichloracetone formed by direct substitution has the structure $CHCl_2.CO.CH_3$. The isomeric compound of the structure $CH_2Cl.CO.CH_2Cl$ can not be prepared from acetone. It is prepared from glycerol by the steps indicated by the following formulas: —

$$\mathrm{CH_2OH.CHOH.CH_2OH} \xrightarrow{\mathrm{HCl}} \mathrm{CH_2Cl.CHOH.CH_2Cl} \xrightarrow{\mathrm{O}} \mathrm{CH_2Cl.CO.CH_2Cl}$$

These facts in regard to the dichloracetones have been mentioned as an illustration of an important principle in organic chemistry. In most cases all the possible substitution-products of a compound are not formed as the result of the action of the substituent on the compound. The position taken by the entering atom is determined by the configuration of the molecule and the nature of the atoms which it contains. When it is desired to prepare a derivative of a compound which is not formed by direct substitution, indirect methods must be resorted to. The method used in the preparation of the symmetrical dichloracetone is an example. Another example is furnished by the β-halogen derivatives of propionic acid, which are prepared indirectly from glycerol.

The accumulation of halogen atoms in ketones brings about a change in chemical properties similar to that observed in the analogous derivatives of aldehydes. Hexachloracetone, for example, forms a hydrate with water $(CCl_3)_2CO.H_2O$, and, like other highly substituted derivatives of acetone, is decomposed by alkalies. It is probable that the formation of chloroform from acetone and bleaching-powder is the result of the decomposition of trichloracetone, which appears to be an intermediate product in the reaction: —

$$CH_3.CO.CH_3 \xrightarrow{Cl_2} CCl_3.CO.CH_3 \xrightarrow{Ca(OH)_2} CCl_3H + (CH_3COO)_2Ca$$

Acetone is likewise converted into bromoform, $CHBr_3$, when it is treated in aqueous solution with sodium hydroxide and bromine. Iodoform, CHI_3, is formed in a similar way.

AMINO-ACIDS

A great many compounds are known which contain two or more characteristic groups, one of which owes its properties to the presence of nitrogen. Only the amino-acids and certain of their derivatives will be discussed here. The simplest member of this class is amino-formic acid, $NH_2.COOH$, which is usually called carbamic acid (**183**). Only the salts of the acid are known. Amino-acetic acid, $NH_2.CH_2COOH$, is a typical member of the series of amino-acids. The formula assigned to it indicates that the acid is derived from acetic acid by the replacement of a hydrogen atom in the methyl group by an amino group, or from methylamine by the replacement of hydrogen by the carboxyl group. The reactions of the acid are in accord with this view of its structure.

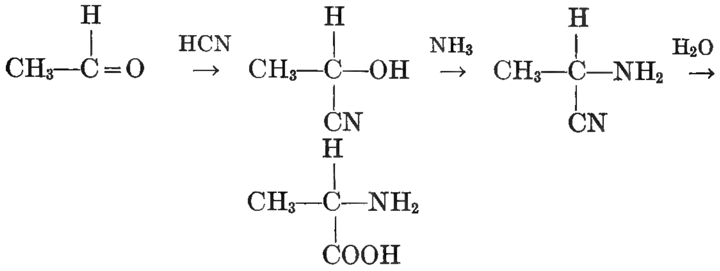
269. Preparation of Amino-acids. — Amino-acids may be prepared by the action of ammonia on halogen derivatives of the acids. The reaction is analogous to that by which amines are formed: —

$$NH_3 + ClCH_2COOH = NH_2CH_2COOH + HCl$$
$$NH_3 + ClCH_3 = NH_2CH_3 + HCl$$

In both cases the compounds are obtained as salts, from which the acid or amine can be liberated by a base. When derivatives of ammonia are used, substitution-products of the amino-acids are formed: —

$$CH_3NH_2 + ClCH_2COOH = CH_3NH.CH_2COOH + HCl$$

Another method of preparation which has been frequently used to synthesize the amino-acids obtained from certain natural sources, is illustrated by the following formulas: —



$$CH_3-\overset{H}{\overset{|}{C}}=O \xrightarrow{HCN} CH_3-\overset{H}{\overset{|}{\underset{\underset{CN}{|}}{C}}}-OH \xrightarrow{NH_3} CH_3-\overset{H}{\overset{|}{\underset{\underset{CN}{|}}{C}}}-NH_2 \xrightarrow{H_2O}$$
$$CH_3-\overset{H}{\overset{|}{\underset{\underset{COOH}{|}}{C}}}-NH_2$$

270. Reactions of Amino-acids. — The amino-acids form salts with acids and with bases. It is possible that amino-acetic acid is itself a salt that results from the interaction of the amino group and the carboxyl group, which the acid contains. Such a salt would be decomposed when treated with a strong acid or base, and a salt with the acid or base would be formed.

The amino group present in these acids takes part in reactions characteristic of amines. When treated with nitrous acid, the amino-acids are converted into hydroxy-acids: —

$$NH_2CH_2COOH + HNO_2 = HOCH_2COOH + N_2 + H_2O$$
$$NH_2CH_3 + HNO_2 = HOCH_3 + N_2 + H_2O$$

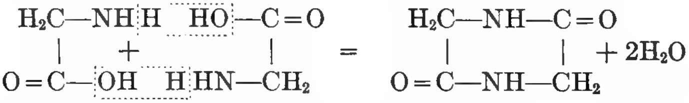
With acyl chlorides compounds related to amides are formed:—

$$CH_3COCl + NH_2CH_2COOH = CH_3CO.NHCH_2COOH + HCl,$$
$$CH_3COCl + NH_3 = CH_3CO.NH_2 + HCl$$

The esters of amino-acids are prepared by the application of one of the general methods of preparing esters, namely, the treatment of the mixture of an acid and an alcohol with hydrogen chloride. The product obtained in this case is the hydrochloride of the amino-ester. The free ester can be isolated by careful treatment with an alkali. The esters of the amino-acids can be distilled without decomposition under diminished pressure, whereas the free acids are decomposed when heated. This fact has been utilized in the separation of the amino-acids which are obtained as the result of the hydrolysis of proteins.

271. The amino-acids decompose with more or less readiness when heated. The changes which take place bear a striking analogy to those observed in the case of the hydroxy-acids (**236**).

When the α-amino-acids are heated two molecules of the acid lose two molecules of water as the result of the interaction of the hydroxyl and amino groups:—

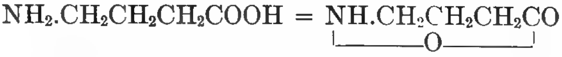


$$\begin{array}{lcl} H_2C—NH\,H \quad HO—C=O & & H_2C—NH—C=O \\ \;\;| \qquad + \qquad\quad | & = & \;\;| \qquad\qquad\; | \quad + 2H_2O \\ O=C—OH \quad H\,HN—CH_2 & & O=C—NH—CH_2 \end{array}$$

The β-acids lose ammonia when heated:—

$$NH_2.CH_2CH_2COOH = CH_2{:}CHCOOH + NH_3$$

The γ-acids lose water and form compounds called *lactams* on account of their relation to lactones, which are formed from γ-hydroxy-acids:—

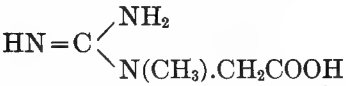


$$NH_2.CH_2CH_2CH_2COOH = \underbrace{NH.CH_2CH_2CH_2CO}_{O}$$

272. Glycine, NH_2CH_2COOH, glycocoll, amino-acetic acid, can be obtained from glue or certain other proteins by boiling with dilute sulphuric acid. The acid has a sweet taste; it is often called glycocoll, the name being derived from the Greek words signifying sweet and glue. It is obtained from a number of natural sources. It is formed as one of the products of hydrolysis of hippuric acid, $C_6H_5CONH.CH_2COOH$, which occurs in the urine of horses, and of taurocholic acid and glycocholic acid, which occur in the bile. It can be prepared synthetically from ammonia and chloracetic acid. The acid crystallizes from water, and melts with decomposition at 232°. Glycine forms salts with acids, such as those of the composition $HCl.NH_2CH_2COOH$ and $HNO_3.NH_2CH_2COOH$. The copper salt, which crystallizes from water has the formula $(NH_2CH_2COO)_2$-$Cu.H_2O$.

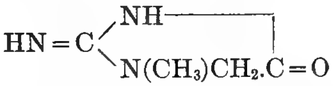
Sarcosine is a methyl derivative of glycine, $CH_3NH.CH_2COOH$. It is found in flesh, and is a constituent of meat extract.

273. Creatine is also one of the so-called meat extractives. It is related to sarcosine and guanidine. Its formula is, —

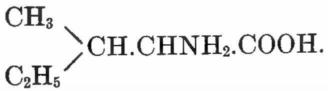


$$HN{=}C\begin{matrix}\diagup NH_2\\ \diagdown N(CH_3).CH_2COOH\end{matrix}$$

Creatine passes by loss of water into *creatinine*, which is present in flesh, and in small quantity in urine. The formula assigned to creatinine is, —

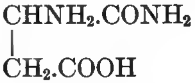


274. Alanine, $CH_3.CHNH_2.COOH$, α-aminopropionic acid, may be prepared by the action of ammonia on α-chloropropionic acid. It is an important decomposition-product of proteins. *Serine*, which is the β-hydroxyl derivative of alanine, is also obtained from proteins. It has been synthesized from glycollic aldehyde by the reactions indicated in the second method of preparing amino-acids described above (**269**).

275. Leucine, $(CH_3)_2CH.CH_2.CHNH_2.COOH$, α-amino-isocaproic acid, is found in a number of the organs of the body, and is obtained from proteins by hydrolysis. It has been synthesized from isovaleric aldehyde. *Isoleucine*, is an isomer of the formula  $\begin{matrix}CH_3\\ C_2H_5\end{matrix}\!\!>CH.CHNH_2.COOH$. It has been shown that the isoamyl alcohol and active amyl alcohol which are the chief constituents of the fusel oil formed in the fermentation of grain, are produced as the result of the decomposition of the proteins of the grain which yield leucine and isoleucine on hydrolysis. When sugar is fermented with pure yeast, amyl alcohols are not formed. In the presence of leucine, isoamyl alcohol, $(CH_3)_2CHCH_2CH_2OH$, and in the presence of isoleucine, active amyl alcohol, $CH_3.C_2H_5.CH.CH_2OH$, are formed.

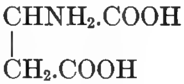
276. Ornithine, $NH_2.CH_2.CH_2.CH_2.CHNH_2.COOH$, α, δ-diaminovaleric acid, and *lysine*, α, ϵ-diaminocaproic acid, are obtained from proteins. The former is converted into putrescine, $NH_2(CH_2)_4NH_2$, and the latter into cadaverine, $NH_2(CH_2)_5NH_2$, by putrefactive bacteria.

277. α-Asparagine is an example of an acid amide which contains an amino group. Its formula is, —



$$\begin{array}{l} CHNH_2.CONH_2 \\ | \\ CH_2.COOH \end{array}$$

Asparagine occurs in asparagus, beets, peas, beans, and in a great variety of plants. The NH_2 groups which asparagine contains do not react alike. One is present in an amide group $CONH_2$; the other is joined to carbon which is not directly linked to oxygen. When asparagine is boiled with a solution of an alkali, but one-half of the nitrogen is removed as ammonia. The resulting product is a salt of aspartic acid, —



$$\begin{array}{l} CHNH_2.COOH \\ | \\ CH_2.COOH \end{array}$$

The Nature of Radicals and the Effect of Structure on the Activity of Acids

278. It has been repeatedly pointed out that the organic radicals differ markedly in chemical nature. Some, like ethyl, are positive, while others, like acetyl, are negative. It has been shown that a more or less definite idea of the nature of any particular radical may be gained by a study of the properties of the compound of the radical with the hydroxyl group. If an element other than hydrogen is present in a radical its general effect can be foretold from a knowledge of the chemical properties of the element itself. Oxygen, for example, is a negative element, and it has been seen that when it is introduced into a radical in the place of hydrogen, it brings about a marked change in properties. Thus, the ethyl radical, CH_3CH_2-, is positive, while acetyl, CH_3CO-, is negative. Sulphur, which resembles oxygen, and the hydroxyl group produce a similar effect. On the other hand, the amino group, NH_2, which is derived from the positive ammonia molecule, increases the positive nature of a radical into which it is introduced.

This method of studying the nature of radicals is far from satisfactory, and a method of arriving at a definite quantitative statement of the properties of radicals from this point of view is much needed. Up to the present no such quantitative statement can be made, but it is possible to arrange many radicals, approximately, in order of the property which has been called, for lack of a better expression, their positive or negative nature.

Acids vary greatly in the extent to which they undergo ionization when dissolved in water. Thus, acetic acid, $CH_3CO.OH$, is but slightly ionized, while trichloracetic acid, $CCl_3CO.OH$, is ionized to a high degree. The difference in activity is the result of the fact that the radical in trichloracetic acid is more negative than the radical in acetic acid.

The ionization of organic acids has been studied extensively, and the results obtained are of the greatest value, as they furnish a means of comparing radicals as to their relative positive or negative nature. The extent to which an acid is ionized varies with the concentration of its solution. The comparison of the ionization of two acids is simplified by the fact that a mathematical relation exists between the extent of the ionization of an acid and its concentration, which is represented by the formula,

$$\frac{a^2}{v(1-a)} = K$$

where a is the percentage of the acid which is ionized, v is the volume of the solution which contains one gram-molecular weight of the acid, and K is a constant.[1] It is seen from the formula that of two acids the one which is more highly ionized has the greater constant. The ionization-constants of a number of acids will now be given to illustrate the effect of structure on the activity of acids, and the effect of substituents on the nature of radicals.

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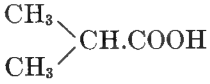
[1] For the derivation of this formula the student should consult a textbook of physical chemistry.

Acid	K	Acid	K
$H.COOH$	.0214	$CH_3CH_2CH_2.COOH$	.00149
$CH_3.COOH$	.00180	 $(CH_3)_2CH.COOH$	.00144
$C_2H_5.COOH$	.00134		
$C_3H_7.COOH$	.00149		
$C_5H_{11}.COOH$	.00145		

In the first column the normal acids are given. It is seen that formic acid is a much stronger acid than acetic acid, which is but slightly more ionized than propionic acid. The alkyl radicals do not appear to differ markedly in chemical nature. The constants of butyric and isobutyric acid, which are given in the last column, are very nearly alike.

The effect of substituents is shown by the following table: —

Acid	K	Acid	K
$CH_3.COOH$	.0018	$CH_2Br.COOH$	.138
$CH_2Cl.COOH$	.155	$CH_2(CN).COOH$	.370
$CHCl_2.COOH$	5.14	$CH_2(OH).COOH$	.0152
$CCl_3.COOH$	121.	$CH_2(SH).COOH$	.0225

The replacement of a hydrogen atom in acetic acid by one chlorine atom increases the constant of the acid 86 times. The second and third atoms do not have as great an effect; the constant of dichloracetic acid is about 33 times as great as that of chloracetic acid, and that of trichloracetic acid 23.5 times as great as that of the disubstituted-acid. Bromacetic acid is almost as strong as chloracetic acid, while cyanacetic acid is over twice as active as the latter. The $-C\equiv N$ radical is accordingly strongly negative. From this point of view it appears remarkable that hydrocyanic acid is such a weak acid. As the cyanogen radical has such strongly negative properties, it seems highly probable that it is not present in hydrocyanic acid, and that the acid has the structure $H-N=C$ and not $H-C\equiv N$.

The relative effect of oxygen and sulphur is shown in the constants for glycolic acid and thioglycolic acid. When sulphur replaces the oxygen of the hydroxyl group it has a marked effect on the constant of an acid: the constant for thioacetic acid, $CH_3.CO.SH$ is 0.469 while that of acetic acid is .0018.

The effect of the position of the substituent on the constant of an acid is shown in the following table: —

Acid	K	Acid	K
$CH_3.CH_2.COOH$	.00134	$HOOC.COOH$	10.
$CH_3.CHOH.COOH$	.0138	$HOOC.CH_2.COOH$	.158
$CH_2OH.CH_2.COOH$	.00311	$HOOC.CH_2CH_2.COOH$	.00665
$CH_2OH.CHOH.COOH$	.0228		

It is seen that the nearer the substituent is to the carboxyl group, the greater is its effect on the ionization constant.

The effect of a double bond is shown in the following table: —

Acid	K	Acid	K
$CH_3.CH_2.COOH$	.00134	$\begin{matrix}HC.COOH\\ \|\\ HC.COOH\end{matrix}$	1.17
$CH_2{=}CH.COOH$	.0056	$\begin{matrix}HC.COOH\\ \|\\ HOOC.CH\end{matrix}$	.093
$\begin{matrix}HC.COOH\\ \|\\ HC.CH_3\end{matrix}$	.0020		
$\begin{matrix}HC.COOH\\ \|\\ CH_3.CH\end{matrix}$	.0036		

The introduction of a double bond leads to an increased activity in the acid. The marked difference between the values of the constants of maleic and fumaric acid is noteworthy. The difference appears to be the result of the positions with respect to each other occupied by the two carboxyl groups. The stereochemical influence is marked in this case. In the tartaric acids this is not so; the ionization constants for *d*-tartaric acid, *l*-tartaric acid, and racemic acid are the same, namely, .097.

PROBLEMS

1. Write equations for reactions by which (*a*) α-bromacrylic acid may be prepared from propionic acid, (*b*) β-bromacrylic acid from propiolic acid, (*c*) α-hydroxybutyric acid from propionic aldehyde, (*d*) malic acid from succinic acid, (*e*) αα-dichlorpropionic acid from lactic acid, (*f*) citric acid from glycerol, (*g*) serine from glycollic aldehyde, (*h*) sarcosine from acetic acid, (*i*) alanine from propionic acid.

2. Write equations for reactions by which the following may be prepared through the aid of the acetoacetic ester synthesis: — (*a*) $CH_3COC_3H_7$,

(*b*) $CH_3COCH.C_2H_5.C_3H_7$, (*c*) C_4H_9COOH, (*d*) $CH_3.C_2H_5.CH.COOH$, (*e*) $CH_3.CHOH.C_4H_9$, (*f*) $CH_3.CH_2.CH.CH_3.C_2H_5$.

3. Write equations for the reactions which take place when the following are heated with a solution of sodium hydroxide: (*a*) $CH_3.CHOCH_3.COOCH_3$, (*b*) $CH_3.CHOH.COOCH_3$, (*c*) $CH_3.CHOCH_3.COOH$, (*d*) $CH_3.CHNH_2.CONH_2$, (*e*) $CH_3.CHNH_2.COOCH_3$, (*f*) $NH_2COCH_2.CHNH_2COOH$.

4. By what chemical tests could you distinguish from each other the following: (*a*) $CH_3.CHCl.COOH$ and $CH_3CH_2.COCl$, (*b*) $CH_3CHCl.CONH_2$ and $CH_3CHNH_2.COCl$, (*c*) $CH_2OH.CH_2Br$ and $CH_2Br.CH_2Br$, (*d*) $CH_3O.CH_2COOH$ and $HOCH_2.COOCH_3$?

5. Write graphic formulas of the compounds obtained by the oxidation of (*a*) lactic acid, (*b*) glyceric acid, (*c*) hydracrylic acid.

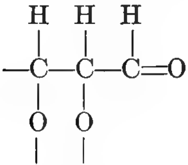
6. Write graphic formulas of the compounds obtained in the conversion of glyceric acid into β-iodopropionic acid by hydriodic acid.

7. Write the graphic formulas of compounds you would expect to be formed by the action of (*a*) heat on malic acid, and (*b*) concentrated nitric acid on tartaric acid.

CHAPTER XV

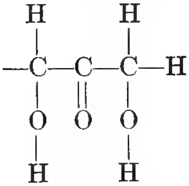
CARBOHYDRATES

279. Many organic compounds are produced as the result of the growth of plants. The more important of these, such as starch, sugar, and cellulose, are called carbohydrates. The name was originally given to the members of this class on account of the fact that the hydrogen and oxygen which they contain are present in the proportion in which these elements are present in water. The relation is shown by writing the formula for sugar, $C_{12}H_{22}O_{11}$, as $C_{12}.11(H_2O)$, and for starch, $C_6H_{10}O_5$, as $C_6.5(H_2O)$. The formulas of certain carbohydrates which have been isolated from natural sources, do not show the simple relation between the hydrogen and oxygen atoms indicated by the name. Rhamnose, for example, which is obtained from the bark of certain trees, has the formula $C_6H_{12}O_5$. A number of compounds which are not carbohydrates contain hydrogen and oxygen atoms in the relation of two of the former to one of the latter; the formula of acetic acid is $C_2H_4O_2$, of lactic acid, $C_3H_6O_3$, and so forth. Notwithstanding these facts the name carbohydrate is retained. The study of the structure of compounds of this class has made it possible to define the term more specifically. The carbohydrates are aldehyde-alcohols, ketone-alcohols, or compounds which are converted by hydrolysis into aldehyde-alcohols or ketone-alcohols. The carbohydrates contain, or are converted by hydrolysis into compounds which contain the arrangement of atoms represented by the formulas,—



$$\begin{array}{ccccccc} & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & \\ & | & & | & & | & \\ - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & =\mathrm{O} \\ & | & & | & & & \\ & \mathrm{O} & & \mathrm{O} & & & \\ & | & & | & & & \\ & \mathrm{H} & & \mathrm{H} & & & \end{array}$$

aldehyde-alcohol



$$\begin{array}{ccccccc} & \mathrm{H} & & & & \mathrm{H} & \\ & | & & & & | & \\ - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & -\mathrm{H} \\ & | & & \| & & | & \\ & \mathrm{O} & & \mathrm{O} & & \mathrm{O} & \\ & | & & & & | & \\ & \mathrm{H} & & & & \mathrm{H} & \end{array}$$

ketone-alcohol

The carbohydrates, or *saccharides* as they are sometimes called, are divided into two classes: those which do not undergo hydrolysis are called *monoses* or *monosaccharides*, and those which are converted into monoses by hydrolysis are called *polyoses* or *polysaccharides.* When the monoses contain the aldehyde group they are classed as *aldoses;* when they contain the ketone group they are called *ketoses.* The number of carbon atoms in a monose is indicated in its name; thus, glucose, $C_6H_{12}O_6$, is a *hexose. Tetroses, pentoses, heptoses, octoses,* and *nonoses* are known. When a polysaccharide yields two molecules of a monosaccharide on hydrolysis it is called a *disaccharide.* Cane sugar is a disaccharide, as on hydrolysis it is converted into one molecule of glucose and one molecule of fructose.

As the hexoses are the most important of the monosaccharides a few typical members of the class will be discussed in some detail.

DEXTROSE

280. Dextrose, *d*-glucose, $C_6H_{12}O_6$, occurs widely distributed in fruits, usually mixed with another sugar called levulose or fructose. It is an important constituent of honey, which contains in addition to dextrose, levulose, dextrin, and cane sugar. It is present in relatively large amounts in grapes; for this reason dextrose is often called grape-sugar. It is present in small quantities in normal urine, but the amount may increase up to 8 to 10 per cent in the case of patients suffering from diabetes.

Dextrose is formed as the result of the hydrolysis of a number of polysaccharides. Starch, dextrin, and maltose are completely converted into dextrose when heated with water in the presence of a small amount of acid. The reaction in the case of starch is represented by the equation, —

$$(C_6H_{10}O_5)_n + nH_2O = nC_6H_{12}O_6$$

and that for maltose by the equation, —

$$C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6$$

Other polysaccharides yield dextrose along with another hexose on hydrolysis. Cane sugar is converted in this way into dextrose and levulose: —

$$\underset{}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{dextrose}}{C_6H_{12}O_6} + \underset{\text{levulose}}{C_6H_{12}O_6}$$

Milk sugar yields dextrose and galactose; the equation for the reaction is the same as that written for cane sugar.

Dextrose crystallizes with difficulty from water, in which it is very soluble. The crystals contain one molecule of water, and are in the form of microscopic six-sided plates, which grow in masses; they melt at 86°. They are obtained most readily by crystallizing dextrose from 80 per cent alcohol. Anhydrous dextrose is obtained from 95 per cent methyl or ethyl alcohol. In this form the carbohydrate melts at 146°. Pure dextrose is approximately three-fifths as sweet as sugar. It is optically active.

281. Specific Rotation of Optically Active Substances. — The extent to which polarized light is rotated by optically active substances varies with different substances. With any substance the angle of rotation depends upon the concentration of the solution, the length of the layer through which the light passes, the temperature, and the wave-length of the light. In order to compare the rotatory power of different compounds standard conditions have been defined. The *specific rotation* of an optically active substance is measured by the angle of rotation which plane polarized light of the wave length corresponding to that of the yellow, D, line of the solar spectrum, undergoes in passing through, at a temperature of 20°, a decimeter column of a solution of the substance having the concentration of one gram in one cubic centimeter. This is expressed by the equations,

$$a = [a]_D l \frac{w}{v} \quad \text{or} \quad [a]_D = \frac{a\ v}{l\ w}$$

where a is the observed angle of rotation, $[a]_D$ is the specific rotation, l length of the column in decimeters, w the weight of substance, and v the volume of the solution.

$[a]_D$ for dextrose is 52.7° If a substance is levorotatory its rotation is expressed as a negative angle, thus, for levulose $[a]_D$ is −93°.

Many optically active substances when dissolved in water form solutions which slowly change in rotatory power until a constant value is finally reached. This phenomenon is called *multirotation* or *birotation*. When ordinary dextrose, which contains one molecule of water of crystallization, is dissolved in water, the specific rotation of the solution is 105.2°. An anhydrous form of dextrose has been prepared which gives as soon as dissolved the specific rotation 22.5°. It is probable the solution obtained from either form of the carbohydrate, which, on standing some hours shows the normal specific rotation, 52.7°, contains a mixture of the two forms in equilibrium. The view has been put forward that carbohydrates which exhibit multirotation may exist as aldehydes or as lactones.

In the case of optically active liquids the specific rotation is defined by the formula $[\alpha]_D = \frac{a}{l\,d}$, where l is the length of the column examined, and d is the density of the liquid.

282. Preparation of Dextrose. — Dextrose is made commercially by hydrolyzing starch with dilute hydrochloric acid (1 to 3 per cent). The mixture is heated to boiling in an open vessel or with superheated steam in a closed vessel. The length of time of heating is determined by the nature of the product desired. If "glucose," which is the commercial name for the thick syrup formed as the result of the partial hydrolysis of starch, is to be made, the reaction is stopped when a test portion of the solution does not give the characteristic blue color which starch forms with iodine. The port-wine color which results indicates the presence of dextrin, which is an intermediate product in the change of starch into dextrose. "Glucose" also contains some maltose, $C_{12}H_{22}O_{11}$. In making "grape sugar," which is almost pure dextrose, the hydrolysis is carried farther. The complete conversion of the starch into dextrose is shown by adding alcohol to the product of hydrolysis; if no precipitate is formed starch and dextrin are absent, as these substances are insoluble in alcohol. Grape sugar is usually obtained in the form of a compact mass of waxy texture. By allowing a concentrated solution of grape sugar to stand at about 35° in contact with a few crystals of dextrose, the larger part of the substance separates as a mass of minute crystals.

Glucose and grape sugar are obtained from the dilute solutions formed as the result of the hydrolysis, by evaporation in vacuum pans after the solutions have been neutralized with sodium carbonate, filtered, and decolorized by treatment with bone-black.

Glucose has a number of important uses. As it is converted into alcohol by fermentation, it is frequently added to the liquids from which wine and beer are to be prepared, in order to increase the percentage of alcohol formed. It is used in dyeing with indigo, in the preparation of jellies and preserves, and as a thickening agent in certain pharmaceutical preparations. It is also used as a table-syrup.

283. Structure of Dextrose. — Dextrose enters into a number of important reactions with other substances. Those which have a bearing on the structure of the carbohydrate will be first considered. Dextrose is reduced by hydrogen, generated from sodium-amalgam and water, to *d*-sorbitol, which is a hexatomic alcohol, —

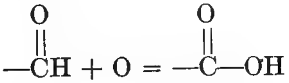
$$CH_2OH.CHOH.CHOH.CHOH.CHOH.CH_2OH$$

This transformation indicates that the carbon atoms in glucose are united in a straight chain.

By careful oxidation dextrose is converted into gluconic acid: —

$$C_6H_{12}O_6 + O = C_6H_{12}O_7$$

The addition of one oxygen atom results in the formation of an acid. This fact indicates that glucose contains an aldehyde group: —



$$-\overset{\overset{O}{\|}}{C}H + O = -\overset{\overset{O}{\|}}{C}-OH$$

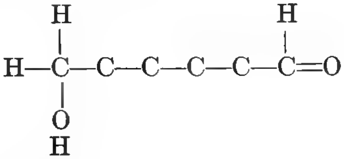
On further oxidation saccharic acid, a dibasic acid, is formed. The change in this case consists in the replacement of two hydrogen atoms by one oxygen atom: —

$$C_6H_{12}O_7 + 2O = C_6H_{10}O_8 + H_2O$$

This reaction shows that gluconic acid and dextrose, from which it is prepared, each contain a primary alcohol group. The change which takes place consists in the conversion of this group into a carboxyl group: —

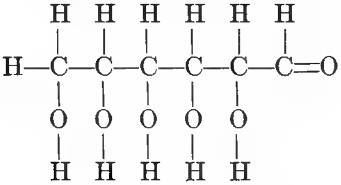
$$-CH_2OH + 2O = -COOH + H_2O$$

As the aldehyde group and the primary alcohol group are both univalent, they must be situated at the ends of the chain of carbon atoms in dextrose. From these facts, then, we draw the conclusion that in dextrose the atoms are united as indicated in the following arrangement: —



$$\begin{array}{ccccccccccccc} & & H & & & & & & & & H & & \\ & & | & & & & & & & & | & & \\ H & - & C & - & C & - & C & - & C & - & C & = & O \\ & & | & & & & & & & & & & \\ & & O & & & & & & & & & & \\ & & H & & & & & & & & & & \end{array}$$

The relation which the oxygen atoms in dextrose bear to the rest of the molecule, is indicated by the fact that when the carbohydrate is treated with acetic anhydride, in the presence of a small amount of zinc chloride, five acetyl groups are introduced into the molecule. This reaction shows that dextrose contains five alcoholic hydroxyl groups. Taken in connection with the reactions just mentioned, it leads to a structure for dextrose which is given in the following formula: —



$$\begin{array}{ccccccccccccc} & & H & & H & & H & & H & & H & & H \\ & & | & & | & & | & & | & & | & & | \\ H & - & C & - & C & - & C & - & C & - & C & - & C = O \\ & & | & & | & & | & & | & & | & & \\ & & O & & O & & O & & O & & O & & \\ & & | & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & H & & \end{array}$$

284. Chemical Properties of Dextrose. — The reactions of dextrose are in accord with the formula which has been assigned to it. It reacts as an aldehyde with an ammoniacal solution of silver oxide, with Fehling's solution, and with alkalies. An alkaline solution of dextrose precipitates selenium, tellurium, gold, platinum, and certain other metals from their salts.

Dextrose forms an oxime with hydroxylamine, which melts at 137°, and a phenylhydrazone, which melts at 145°. Both compounds are very soluble in water. When dextrose is heated in aqueous solution with an excess of phenylhydrazine over that required to form the hydrazone, a reaction takes place in which one molecule of the carbohydrate reacts with three molecules of the hydrazine. The substance formed is called an *osazone.* It is a compound which is difficultly soluble in water, crystallizes well, and has a definite melting-point. Other sugars form osazones, which can be readily purified. The determination of the melting-points of the osazones serves as a convenient means of identifying sugars which either do not melt, or can not be readily obtained in pure condition.

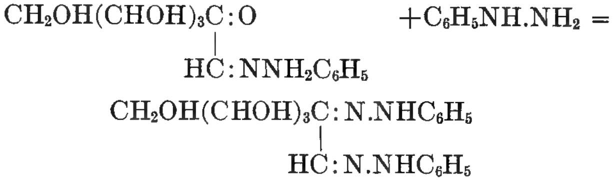
In the conversion of a sugar into an osazone, a hydrazone is first formed, the reaction being analogous to that between an aldehyde and phenylhydrazine: —

$$CH_2OH(CHOH)_4CHO + C_6H_5NH.NH_2 =$$
$$CH_2OH(CHOH)_4CH{:}N.NHC_6H_5 + H_2O$$

In the presence of an excess of phenylhydrazine, two hydrogen atoms are removed from the hydrazone, and a molecule of phenylhydrazine is reduced to ammonia and aniline, $C_6H_5.NH_2$:—

$$C_6H_5NH.NH_2 + 2H = C_6H_5NH_2 + NH_3$$

The product formed from the hydrazone by the loss of two hydrogen atoms interacts with more phenylhydrazine and forms an osazone: —



$$\begin{array}{lll} CH_2OH(CHOH)_3C{:}O & & +C_6H_5NH.NH_2 = \\ \qquad\qquad\qquad\quad | & & \\ \qquad\qquad\qquad HC{:}NNH_2C_6H_5 & & \\ & CH_2OH(CHOH)_3C{:}N.NHC_6H_5 & \\ & \qquad\qquad\qquad\quad | & \\ & \qquad\qquad\qquad HC{:}N.NHC_6H_5 & \end{array}$$

The osazone formed from dextrose (*d*-glucose) is called *d*-glucosazone. It crystallizes from water in yellow needles and melts at 204°–205°.

Dextrose forms addition-products with certain salts, oxides, and anhydrides. A compound of the composition $2C_6H_{12}O_6.NaCl.H_2O$ is obtained in the form of crystals from diabetic urine. Other compounds with sodium chloride have the formulas, —

$$C_6H_{12}O_6.NaCl \quad \text{and} \quad C_6H_{12}O_6.2NaCl$$

Compounds which contain calcium oxide, barium oxide, and zinc oxide are known. One of the compounds which contains calcium oxide has the formula $C_6H_{12}O_6.CaO$.

Dextrose is fermented by the enzyme *zymase*, which is present in yeast; the products are alcohol and carbon dioxide: —

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2$$

As the result of the action of the enzyme in putrid cheese, it is converted into lactic acid and butyric acid.

285. Enzymes. — The chemical change by which glucose is converted into alcohol and carbon dioxide by yeast is an example of what is called fermentation. The process consists in the conversion of an organic compound into simpler substances through the agency of living organisms or the products formed by the growth of such organisms. When fermentation was first studied it was thought that the changes produced were associated in some way with the life processes of the organism which induced fermentation. It was shown later, however, by Buchner, that fermentation was brought about in certain cases by complex substances produced by the living organism. By grinding yeast with sand and subjecting the resulting mixture to great pressure, a juice was obtained which brought about the fermentation of glucose. It was shown by biological tests that the juice did not contain living cells or living protoplasm; its ability to ferment sugar solution was due to the presence of a complex organic substance of unknown composition, which belongs to the class of compounds known as proteins. This substance, which is called *zymase,* is an enzyme. The term enzyme is applied to the substances secreted by living cells, which cause fermentation in the absence of the cell. As typical enzymes may be mentioned: *ptyalin* of the saliva, which converts starch into maltose; *invertase,* which hydrolyzes cane sugar into glucose and fructose; and *pepsin* of the gastric juice, which splits proteins into peptones.

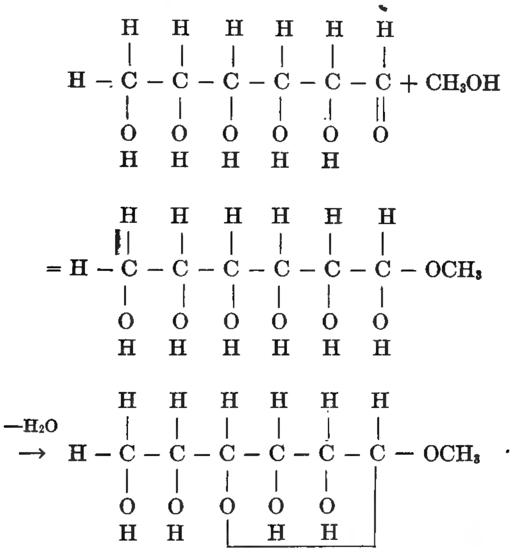
A study of the action of enzymes has led to the conclusion that they act catalytically, and that each enzyme produces a specific effect. Enzymes are soluble in water, and insoluble in alcohol. They lose their activity when their aqueous solutions are heated to boiling, but are not destroyed when heated at 100° after careful drying.

286. Glucosides. — Dextrose occurs in nature in combination with various substances. These compounds, which are called glucosides, are, in most cases, very complex in composition. But a few can be mentioned here. *Aesculin,* $C_{15}H_{16}O_9.1\frac{1}{2}H_2O$, occurs in the bark of the horse-chestnut tree; on hydrolysis it yields dextrose and aesculetin, $C_9H_6O_4$. *Amygdalin,* $C_{20}H_{27}NO_{11}.3H_2O$, occurs in bitter almonds and in the kernels of peaches, plums, and cherries. It is decomposed by dilute acids into glucose, benzaldehyde, C_6H_5CHO, and hydrocyanic acid. *Myronic acid*, $C_{10}H_{17}NS_2O_9.H_2O$, is found as a potassium salt in black mustard seed. When hydrolyzed by the enzyme *myrosin*, it is converted into dextrose, potassium sulphate, and allyl isosulphocyanate, $C_3H_5.NCS$.

Compounds which resemble certain glucosides have been prepared from sugars and alcohols. Dextrose and methyl alcohol react, for example, in the presence of hydrochloric acid to form a compound by loss of water: —

$$C_6H_{12}O_6 + CH_3OH = C_7H_{14}O_6 + H_2O.$$

The condensation-product resembles glucosides in that on hydrolysis it yields dextrose. It does not reduce Fehling's solution and does not contain, therefore, an aldehyde group. It is probable that the condensation takes place according to the following formulas: —

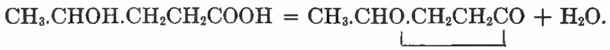


$$\begin{array}{ccccccccccccc}
 & & H & & H & & H & & H & & H & & H \\
 & & | & & | & & | & & | & & | & & | \\
H & - & C & - & C & - & C & - & C & - & C & - & C + CH_3OH \\
 & & | & & | & & | & & | & & | & & \| \\
 & & O & & O & & O & & O & & O & & O \\
 & & H & & H & & H & & H & & H & &
\end{array}$$

$$\begin{array}{cccccccccccccc}
 & & & H & & H & & H & & H & & H & & H \\
 & & & | & & | & & | & & | & & | & & | \\
= & H & - & C & - & C & - & C & - & C & - & C & - & C - OCH_3 \\
 & & & | & & | & & | & & | & & | & & | \\
 & & & O & & O & & O & & O & & O & & O \\
 & & & H & & H & & H & & H & & H & & H
\end{array}$$

$$\begin{array}{cccccccccccccc}
 & & & H & & H & & H & & H & & H & & H \\
\overset{-H_2O}{\longrightarrow} & & & | & & | & & | & & | & & | & & | \\
 & H & - & C & - & C & - & C & - & C & - & C & - & C - OCH_3 \\
 & & & | & & | & & | & & | & & | & & | \\
 & & & O & & O & & O & & O & & O & & | \\
 & & & H & & H & & \lfloor & & H & & H & & \rfloor
\end{array}$$

According to this view the reaction consists in the addition of a molecule of methyl alcohol to the aldehyde group, and the subsequent elimination of a molecule of water. The hydrogen removed from the carbohydrate is assumed to be the one in the hydroxyl group joined to the γ-carbon atom, on account of the fact that a hydrogen atom so situated in a molecule, is known to enter very readily into condensations. It will be recalled that γ-lactones are formed with the greatest ease; some γ-hydroxy acids spontaneously lose water and pass into lactones when liberated from their salts: —



$$CH_3.CHOH.CH_2CH_2COOH = CH_3.CH\underbrace{O.CH_2CH_2CO} + H_2O.$$

The structure of the artificial glucosides has been discussed, as it is probable that the disaccharides are formed from two molecules of monosaccharides by a condensation similar to that in the case of a monosaccharide and a simple alcohol. Such a condensation is possible as the monosaccharides are alcohols.

d-FRUCTOSE

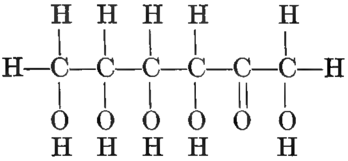
287. ***d*-Fructose**, fruit sugar, $C_6H_{12}O_6$, occurs widely distributed in plants associated with dextrose and cane sugar. It is usually called levulose on account of the fact that it is levorotatory: $[\alpha]_D = -93°$. In the systematic naming of the monoses the letter prefixed to the name does not indicate the direction in which the carbohydrate rotates the plane of polarized light. *d*-Fructose is so-called because it can be formed from *d*-glucose. The alcohol formed by the reduction of *d*-glucose is *d*-sorbitol, and the acids formed by its oxidation are *d*-gluconic acid, and *d*-saccharic acid. The names of the products formed by the reduction or oxidation of *l*-glucose and *i*-glucose are likewise prefixed by the letters *l* or *i*, respectively.

Levulose is a product of the hydrolysis of a number of carbohydrates. Cane sugar yields dextrose and levulose, and raffinose, a trisaccharide, yields levulose, dextrose, and galactose. Levulose is best prepared by hydrolyzing with dilute sulphuric acid inulin, a starch which occurs in dahlia tubers: —

$$(C_6H_{10}O_5)_x + xH_2O = xC_6H_{12}O_6$$

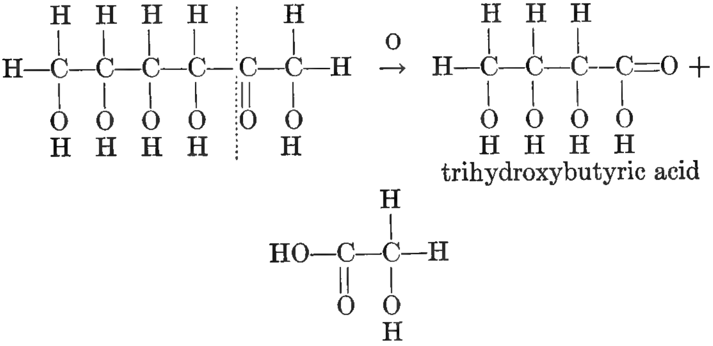
Levulose crystallizes in fine, colorless, rhombic needles, which melt at 95°. It is converted by yeast into alcohol and carbon dioxide.

288. Structure of *d*-Fructose. — As *d*-fructose yields *d*-sorbitol and *d*-mannitol on reduction, it must contain a straight chain of six carbon atoms. Acetic anhydride converts the carbohydrate into a penta-acetate, a fact which indicates that it contains five hydroxyl groups. On oxidation *d*-fructose does not yield an acid which contains six carbon atoms; it is, therefore, not an aldehyde. It is a ketone, however, as it forms a phenylhydrazone. The oxidation-products vary with the nature of the oxidizing agent; mercuric oxide in the presence of barium hydroxide yields trioxybutyric acid and glycollic acid. All the facts stated lead to the conclusion that the structure of *d*-fructose is best represented by the formula, —



$$\mathrm{H-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\underset{\overset{\|}{O}}{C}-\overset{H}{\underset{OH}{C}}-H}$$

The formation of glycollic acid and trioxybutyric acid as the result of the oxidation of fructose can be readily interpreted. It will be remembered that when ketones are oxidized two acids are formed as the result of the splitting of the molecule at the carbonyl group. In the oxidation of fructose by mercuric oxide, this decomposition takes place between the carbonyl and the secondary alcohol groups: —

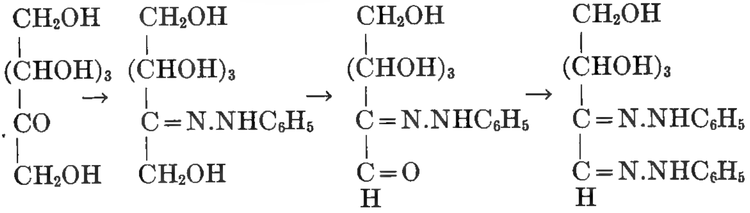


$$\mathrm{H-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\underset{\overset{\|}{O}}{C}-\overset{H}{\underset{OH}{C}}-H \xrightarrow{O} H-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\overset{H}{\underset{OH}{C}}-\underset{OH}{C}=O + HO-\underset{\overset{\|}{O}}{C}-\overset{H}{\underset{OH}{C}}-H}$$

trihydroxybutyric acid

glycollic acid

289. Chemical Properties of *d*-Fructose. — The carbohydrate forms a hydrazone when treated with phenylhydrazine; when heated in aqueous solution with an excess of the hydrazine, an osazone is formed, which is identical with *d*-glucosazone. The reaction in this case is explained in the following manner: A hydrazone is first formed as the result of the interaction of the carbonyl group and phenylhydrazine. Excess of the latter oxidizes the primary alcohol group to an aldehyde group, which reacts with more hydrazine in the usual way. The changes are expressed by the following formulas: —



$$\begin{array}{l}CH_2OH\\ |\\ (CHOH)_3\\ |\\ CO\\ |\\ CH_2OH\end{array}\rightarrow\begin{array}{l}CH_2OH\\ |\\ (CHOH)_3\\ |\\ C=N.NHC_6H_5\\ |\\ CH_2OH\end{array}\rightarrow\begin{array}{l}CH_2OH\\ |\\ (CHOH)_3\\ |\\ C=N.NHC_6H_5\\ |\\ C=O\\ H\end{array}\rightarrow\begin{array}{l}CH_2OH\\ |\\ (CHOH)_3\\ |\\ C=N.NHC_6H_5\\ |\\ C=N.NHC_6H_5\\ H\end{array}$$

d-Fructose reduces Fehling's solution. It will be recalled that most ketones are not oxidized by this reagent (**158**). While ketones which contain the arrangement of atoms represented by the symbols $-CH_2-\overset{O}{\overset{\|}{C}}-CH_2-$, are not affected by mild oxidizing agents, those which contain a hydroxyl group linked to a carbon atom adjoining a carbonyl group, $-\underset{\underset{H}{\underset{O}{|}}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-CH_2-$, are readily oxidized.

290. *i*-**Fructose**, $C_6H_{12}O_6$, is formed as the result of the polymerization of formaldehyde. This takes place when a solution of the aldehyde which contains calcium hydroxide is allowed to stand some time. The product of the polymerization, called *formose*, is a mixture of sugars which contains *i*-fructose. The carbohydrate is also formed by the action of a one-percent solution of sodium hydroxide on glyceric aldehyde, $CH_2OH.CHOH.CHO$. On account of the fact that the synthesis in this way was effected from acrolein, the sugar was originally called *acrose*. Investigation proved later that acrose is *i*-fructose.

291. *d*-**Galactose**, $C_6H_{12}O_6$, is formed along with dextrose by the hydrolysis of milk sugar (lactose), $C_{12}H_{22}O_{11}$, and is a product of the oxidation of dulcitol, a hexatomic alcohol which occurs in certain plants. Galactose forms crystals which melt at 168°. It is dextrorotatory, $[\alpha]_D = 81.5°$, undergoes fermentation, and is an aldose. Oxidizing agents convert *d*-galactose into *d*-galactonic acid, $CH_2OH(CHOH)_4COOH$, and into mucic acid, $COOH.(CHOH)_4.COOH$.

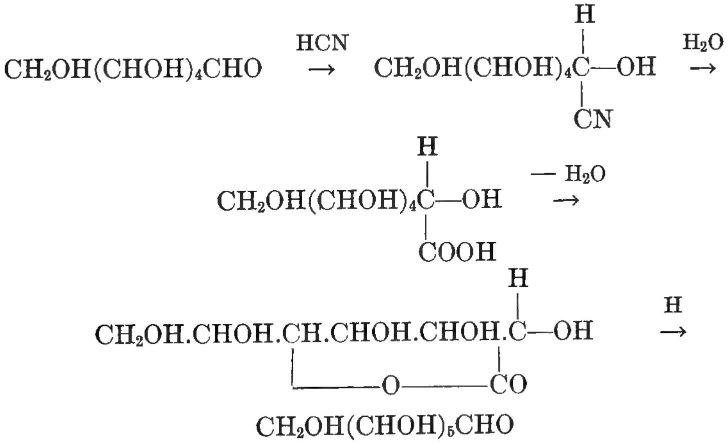
The formula assigned to the aldoses indicates that there should be sixteen different arrangements of the atoms in space, and, consequently, sixteen stereo-isomeric compounds of the structure $CH_2OH(CHOH)_4CHO$ should be capable of existence. Eleven aldohexoses, and five racemic forms made by the combination of dextro and levo modifications have been prepared. Among these are *l*-glucose, *i*-glucose, *l*-galactose, *i*-galactose, and the three forms of mannose. All these forms may be reduced to hexatomic alcohols and oxidized to penta-hydroxy-monobasic acids.

SYNTHESIS OF MONOSES

292. A number of methods of synthesizing the monoses have been devised. The simplest of these is the oxidation of a hexatomic alcohol to the corresponding aldehyde: —

$$CH_2OH(CHOH)_4CH_2OH + O = CH_2OH(CHOH)_4CHO + H_2O$$

A second method, which is important on account of the fact that it serves to pass from one sugar to another containing one more carbon atom, is based on the reaction which aldehydes and ketones undergo with hydrocyanic acid. The steps in the process can be best understood from an examination of the formulas of the substances involved in a typical example: —



$$CH_2OH(CHOH)_4CHO \xrightarrow{HCN} CH_2OH(CHOH)_4\overset{H}{\underset{CN}{C}}—OH \xrightarrow{H_2O}$$

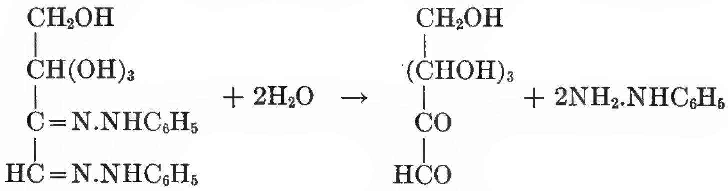
$$CH_2OH(CHOH)_4\overset{H}{\underset{COOH}{C}}—OH \xrightarrow{—H_2O}$$

$$CH_2OH.CHOH.\underset{\lfloor\!\!-\!\!-\!\!-\!\!-O-\!\!-\!\!-\!\!-\!\!-}{CH}.CHOH.CHOH.\overset{H}{\underset{\rfloor CO}{C}}—OH \xrightarrow{H}$$

$$CH_2OH(CHOH)_5CHO$$

The steps are these: hydrocyanic acid is first added to the aldehyde group, the nitrile is next converted into an acid by hydrolysis, the acid which results loses water and passes into a γ-lactone, and, finally, this on reduction yields an aldehyde. In this way a hexose can be converted into a heptose. It should be noted that the process involves the application of reactions which have already been emphasized in the case of simple compounds.

A third synthetic method serves to convert an aldose into a ketose. When an osazone is warmed with concentrated hydrochloric acid, the phenylhydrazine residues are replaced by oxygen atoms and a compound is formed which is called an *osone:* —



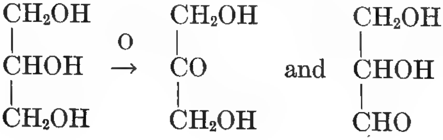
$$\begin{array}{l} CH_2OH \\ | \\ CH(OH)_3 \\ | \\ C{=}N.NHC_6H_5 \\ | \\ HC{=}N.NHC_6H_5 \end{array} + 2H_2O \rightarrow \begin{array}{l} CH_2OH \\ | \\ (CHOH)_3 \\ | \\ CO \\ | \\ HCO \end{array} + 2NH_2.NHC_6H_5$$

When an osone is treated with zinc and acetic acid the aldehyde group which it contains is reduced to a primary alcohol group; the resulting compound is a ketose. In this way *d*-glucose can be converted into *d*-fructose.

A fourth method is used to convert a ketose into an aldose. The ketose is reduced by sodium-amalgam to a hexatomic alcohol; this on oxidation yields a monobasic acid, which is converted into a lactone; and, finally, the lactone is reduced to an aldehyde, which is an aldose.

TRIOSES, TETROSES, PENTOSES

293. Compounds which contain the groups $-CHOH.CHO$ and $-CHOH.CO.CHOH-$ show many of the properties of the hexoses. When glycerol is treated with mild oxidizing agents it is converted into a substance called *glycerose*, which consists essentially of dihydroxyacetone; glyceric aldehyde is also formed: —

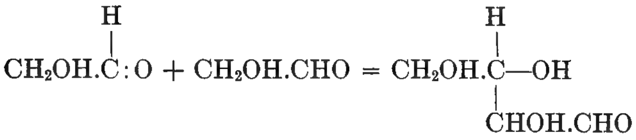


$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} \xrightarrow{O} \begin{array}{l} CH_2OH \\ | \\ CO \\ | \\ CH_2OH \end{array} \quad \text{and} \quad \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CHO \end{array}$$

Glycerose forms an osazone, which melts at 131°. Glyceric aldehyde, which shows the properties of the aldoses, may be prepared from acrolein as indicated here: —

$$CH_2{=}CH.CHO \xrightarrow{Br_2} CH_2Br.CHBr.CHO \xrightarrow{Ba(OH)_2} CH_2OH.CHOH.CHO$$

294. Erythrose, $C_4H_8O_4$, is obtained as the result of the oxidation of erythritol, a tetratomic alcohol. A tetrose can be formed by the polymerization of glycolic aldehyde. The reaction is an example of the aldol condensation (**147**): —



$$CH_2OH.\overset{\overset{H}{|}}{C}{:}O + CH_2OH.CHO = CH_2OH.\underset{\underset{CHOH.CHO}{|}}{\overset{\overset{H}{|}}{C}}—OH$$

As in the simple condensation of aldehyde itself, a molecule of the aldehyde adds to the CHO group. In the addition a hydrogen atom unites with the oxygen, and the rest of the molecule to the carbon atom.

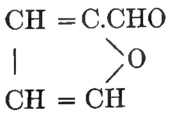
295. Arabinose and Xylose, $C_5H_{10}O_5$, are stereoisomeric pentoses, which have been shown to have the structure,

$$CH_2OH.CHOH.CHOH.CHOH.CHO,$$

by the methods which have been illustrated in the case of the aldohexoses. Both carbohydrates are formed as the result of the hydrolysis of natural polysaccharides called pentosans; gum arabic or cherry gum gives arabinose, and straw, wood, bran, and other substances give xylose. *Rhamnose* is a methyl derivative of a pentose, $CH_3.C_5H_9O_5$; it is obtained by the hydrolysis of a number of natural substances. All pentoses exhibit a reaction which serves to distinguish them from the other sugars. When a pentose or a pentosan is heated with dilute sulphuric acid, furfuraldehyde is formed: —

$$C_5H_{10}O_5 = C_5H_4O_2 + 3H_2O$$

The structure of furfuraldehyde (furfural) has been determined to be that represented by the formula,



The presence of the aldehyde is shown by treating the product of the reaction with aniline, $C_6H_5.NH_2$, and hydrochloric acid; with these reagents the aldehyde produces an intense red dye. When warmed with hydrochloric acid and phloroglucinol (**453**) pentosans and pentoses produce a cherry-red coloration.

DISACCHARIDES

296. A number of disaccharides occur in nature widely distributed in plants, and others are formed in the partial hydrolysis of polyoses. The members of this class of compounds differ among themselves in chemical properties; some, like cane sugar, do not reduce Fehling's solution, while others, like milk sugar, are oxidized by this reagent. The more important bioses are cane sugar, milk sugar, and maltose. They will be described as they are typical members of the class.

Sucrose (cane sugar, saccharose), $C_{12}H_{22}O_{11}$, occurs in sugar-cane, beets, sorghum, the sugar maple, coffee, walnuts, almonds, and in many other substances. It is present in the blossoms of many plants, and is a constituent of honey. Sucrose crystallizes from water in well formed monoclinic prisms. It is soluble in about one-half its weight of cold water; at 50° it is soluble in one-fourth its weight of water. Sucrose melts at 160°, and on cooling solidifies to a white glassy mass. If sugar is heated at or just above its melting-point for some time, it solidifies on cooling to a light brown transparent mass, which is called *barley-sugar*. When heated to 210° it loses water and forms an amorphous light brown substance called *caramel*, which is much used as a flavoring and coloring material. As the temperature is increased deep-seated decomposition takes place; gases are evolved, the substance darkens in color, and finally a residue of carbon remains. Among the products of decomposition have been isolated carbon dioxide, carbon monoxide, methane, ethylene, acetylene, water, acetone, formic acid, acetic acid, aldehyde, and acrolein. Sucrose is dextrorotatory; $[\alpha]_D = 66.5°$.

Sugar is usually prepared from sugar-cane, which contains about 18 per cent sugar, or from beets, which contain from 12 to 15 per cent sugar. The process employed in the extraction of sugar from beets is, in general, the same as that used when sugar-cane is the source of the carbohydrate. The details are different, however, on account of the fact that beets contain certain substances which render the preparation of pure sugar more difficult. In brief, the process consists in the separation of the juice from the insoluble woody fiber, the precipitation from the solution of soluble acids and albuminous substances, the evaporation of the solution to crystallization, and the separation of the crystals from the mother-liquor. When sugar-cane is used, the juice is expressed by passing the cane through rolls; in the case of beets the sugar is removed by extracting with water the beets which have been cut into very small pieces. The solution is next treated with milk of lime and heated to boiling when the calcium salts of the acid present, such as phosphoric, oxalic, and citric acids, are precipitated along with the organic nitrogenous substances and gums. The excess of calcium is removed by passing carbon dioxide through the liquid, which is then separated from solid material by filter-pressing. The clarified juice is, at times, treated with sulphur dioxide to bleach any coloring matter present. The clear solution, which should be slightly alkaline in order to prevent hydrolysis of the sugar when it is heated, is evaporated to crystallization in "vacuum pans," from which the water is removed by boiling the liquid under diminished pressure. At the lower temperature thus obtained the sugar is not greatly affected. When a solution of sugar is evaporated to crystallization in an open vessel, partial decomposition takes place and a brown color is produced. The crystals which separate on cooling are freed from the mother-liquor by means of centrifugal machines. The liquid obtained in this way is called *molasses;* it contains 45 to 50 per cent sucrose and varying amounts of invert sugar, which is a mixture of dextrose and levulose. The molasses obtained from sugar-cane is used as a table syrup or in the manufacture of rum; that from beets can not be used for these purposes, as it contains substances which possess a disagreeable odor. Molasses from both sources is used for making alcohol.

The sugar obtained by the method outlined is not pure; it is brown and contains some syrup in which a number of substances are present. In order to convert it into granulated sugar it is refined. This process consists in dissolving the sugar in water, decolorizing the solution by treatment with bone-black, and crystallizing after evaporation in vacuum pans.

297. Chemical Properties of Sucrose. — Sucrose, like dextrose and other carbohydrates, forms compounds with bases. A number of sucrates (saccharates) which contain calcium have been described. Those of the composition represented by the formulas, $C_{12}H_{22}O_{11}.CaO.2H_2O$ and $C_{12}H_{22}O_{11}.2CaO$, are soluble in water. When a solution containing a soluble calcium sucrate is heated to boiling, the salts are decomposed and a difficultly soluble salt of the formula $C_{12}H_{22}O_{11}.3CaO.3H_2O$ is precipitated. Calcium salts of sucrose are formed in the manufacture of sugar when the juice of sugar-cane is clarified with lime, but are decomposed in the subsequent treatment with carbon dioxide. Strontium and barium also form sucrates. Tricalcium sucrate or tristrontium sucrate is used, at times, in the separation of sugar from molasses which can not be brought to crystallization. Sucrose forms well crystallized compounds with salts, such as $C_{12}H_{22}O_{11}.NaCl.2H_2O$.

The reactions of sucrose indicate clearly that it contains alcoholic hydroxyl groups. Like other polyatomic alcohols it prevents the precipitation of the hydroxides of many metals by sodium hydroxide. It is converted by acetic anhydride into acetates; the one containing the largest number of acetyl groups has the composition $C_{12}H_{14}O_{11}(CH_3CO)_8$.

Sucrose is easily oxidized. The more powerful oxidizing agents, such as chromic acid and potassium chlorate, react with explosive violence. Nitric acid acts energetically, and yields oxalic acid and saccharic acid. Sucrose does not, however, reduce Fehling's solution. This fact is important, as it indicates that sucrose is not an aldehyde and does not contain the arrangement of atoms which is characteristic of a ketose, $-CHOH-CO-CH_2OH$. This conclusion is strengthened by the fact that sucrose does not form a hydrazone with phenylhydrazine.

Sucrose is hydrolyzed when heated with water in the presence of an acid, the products being dextrose and levulose: —

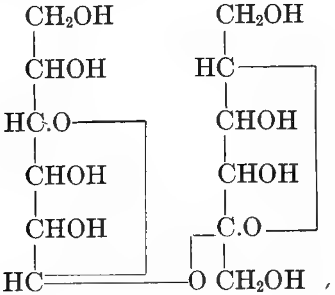
$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

The mixture formed is called *invert sugar*, and the process is known as *inversion*. These names are applied on account of the fact that the direction of the rotation of the plane of polarized light caused by the mixture of the products of hydrolysis, is different from that produced by sucrose. Sucrose is dextrorotatory, $[\alpha]_D = +66.5°$, while a mixture of equal amounts of dextrose and levulose is levorotatory. The specific rotation of invert sugar is the difference between the rotation caused by dextrose, $[\alpha]_D = +52.7°$, and that caused by levulose, $[\alpha]_D = -93$.

The effect of acids on the hydrolysis of cane sugar by water has been carefully studied. It has been found that the rate of the reaction is determined by the nature of the acid used. A comparison of the rate at which the hydrolysis proceeds when molecular quantities of a number of acids are used, brings out the fact that the rate is proportional to the concentration of the hydrogen ions produced as the result of the dissociation of the acid. The catalytic agent is, therefore, the hydrogen ion.

Sucrose does not ferment when treated with *zymase,* the enzyme which brings about the conversion of dextrose and levulose into alcohol and carbon dioxide. It does ferment, however, under the influence of ordinary yeast, which contains in addition to *zymase*, another enzyme, called *invertase* on account of the fact that it causes the inversion of sucrose to dextrose and levulose.

298. The *structure of sucrose* has not been definitely established. The reactions of the carbohydrate indicate that it contains eight hydroxyl groups, and that it does not contain an aldehyde or ketone group. As it yields dextrose and levulose by the addition of one molecule of water, it may be considered as an anhydride of these hexoses. It is apparent that the carbonyl groups which dextrose and levulose contain are involved in the building up of sucrose from these hexoses by the elimination of water. It has not been possible to effect this union in the laboratory, although it takes place, in all probability, in growing plants. Dextrose and levulose are found in unripe fruit; as the fruit ripens these carbohydrates decrease in amount and sucrose is formed. As hydrolysis of sucrose is effected with ease, it is probable that the union of its constituents is effected through oxygen atoms in the way indicated in the case of the glucosides. The structure assigned to sucrose as the result of these considerations is that represented by the formula,



299. Quantitative Determination of Sucrose. — The purity of a sample of sugar, or the amount of sugar in a mixture, is estimated by determining the effect of a solution of the substance to be analyzed on polarized light. If other optically active substances are present, they must be removed, or their effect determined. The instrument used is a saccharimeter. This is a polariscope provided with a scale so graduated that the percentage of sugar is read off directly, when a solution prepared by dissolving a definite weight of the product to be analyzed in a definite volume of water, is examined in the instrument. If the product contains albuminous substances which render it more or less opalescent, it is treated with a solution of basic lead acetate, or aluminum hydroxide, which precipitates such substances. If it is colored, the solution is filtered through bone-black. When a mixture like molasses, which contains, in addition to sucrose, optically active carbohydrates, is to be analyzed, the rotation produced by the solution is first determined: the sugar in the mixture is next inverted, and the rotation of the resulting solution determined. From these two results the amount of sugar present can be calculated.

300. Lactose (milk sugar), $C_{12}H_{22}O_{11}.H_2O$, occurs in the milk of mammals, in which it is present to the extent of from three to five per cent. It is obtained as a by-product in the manufacture of cheese. When rennet is added to milk, the casein and fat which the milk contains are precipitated. The liquid, called whey, after separation from the solid material by pressure, is neutralized with calcium carbonate, filtered, and evaporated to crystallization. The lactose so obtained forms large, hard, rhombic crystals, which contain one molecule of water of crystallization.

Lactose is stable when heated to 100°; above this temperature it loses water slowly, and at 130° is converted into an anhydrous variety. As the temperature is raised decomposition begins, and at 170°–180° the so-called lacto-caramel is formed, which melts at 203.5°. Lactose has a slightly sweet taste. It is soluble in about six parts of cold water, and in about two parts of boiling water. Lactose is dextrorotatory and exhibits the phenomenon of multirotation; $[\alpha]_D = 52.5°$.

Lactose is converted by hydrolysis into dextrose and galactose: —

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$

It reduces Fehling's solution. As the relation between the weight of copper reduced and the weight of the sugar oxidized is definite under fixed conditions, Fehling's solution is used in determining the amount of lactose present in milk.

Lactose forms a hydrazone, osazone, and osone. The composition of these substances indicates that lactose contains one free carbonyl group. It is an anhydride of dextrose and galactose, in which one carbonyl group is involved in the union of the molecules, and one is free. The structure of the products formed on oxidizing lactose indicates that the free carbonyl group is in that part of the molecule which yields dextrose on hydrolysis.

Lactose is not fermented by ordinary yeast, but is converted into lactic acid and alcohol by the so-called lactic ferment, which is found in sour milk.

301. Maltose, $C_{12}H_{22}O_{11}.H_2O$, is formed as the result of the action upon starch of the *diastase* in malt, the *ptyalin* in saliva, and other ferments, and in the partial hydrolysis of starch and dextrin by acids. It is present in commercial glucose, in beer, and probably in bread. It is manufactured on the large scale in the preparation of alcohol and alcoholic beverages (**52**). Maltose crystallizes from water, in which it is readily soluble, in plates, which contain one molecule of water of crystallization. It is obtained from alcohol in wart-like aggregates which are anhydrous. Maltose is dextrorotatory, and shows multirotation; for the anhydrous form $[\alpha]_D = 137°$.

Maltose yields dextrose on hydrolysis. It reduces Fehling's solution, forms a phenylhydrazone, osazone, and osone. It is, accordingly, a glucoside of *d*-glucose, and contains one carbonyl group.

Maltose is fermented by yeast, and is converted almost wholly into alcohol and carbon dioxide.

TRISACCHARIDES

302. Raffinose, $C_{18}H_{32}O_{16}.5H_2O$, is the most important trisaccharide. It yields, as the name trisaccharide implies, three hexose molecules on hydrolysis. Raffinose occurs in the molasses obtained in the manufacture of sugar from beets, in cotton-seed, in barley, and in other grains. The hydrated crystals of raffinose lose their water at 100°. The anhydrous carbohydrate melts at

118°–119°. Raffinose is dextrorotatory; for the hydrated form $[\alpha]_D = 104.5°$. It does not reduce Fehling's solution. On hydrolysis of raffinose, levulose, dextrose, and galactose are formed.

POLYSACCHARIDES

303. The polysaccharides are carbohydrates of high molecular weight in which the carbon, hydrogen, and oxygen are present in the proportion represented by the formula $C_6H_{10}O_5$. Some of the members of the class are probably formed by the condensation of a large number of molecules of hexoses or pentoses with the elimination of water. Starch and cellulose are examples which are important constituents of plants. Other polysaccharides that are simpler in composition, result from the partial hydrolysis of the more complex forms; the dextrins are examples. On complete hydrolysis the polysaccharides yield hexoses or pentoses.

The polysaccharides are either insoluble in water, or, when they apparently dissolve, are present in the form of colloids. When most substances dissolve in a liquid the properties of the solutions are markedly different from those of the solvent. The effect of dissolved substances on the freezing-point and boiling-point of liquids has already been discussed in its relation to the determination of molecular weights. The effect of solutes on a number of other properties of solvents is marked. Certain substances, called colloids, form solutions many properties of which are not markedly different from those of the pure solvent. When such substances dissolve in water, for example, they do not affect apparently the freezing-point or boiling-point of the solvent. It is possible that there is a definite effect, but it is so small that it cannot be measured. These facts indicate that the molecules of colloids are of great size. The formula used in determining molecular weights by the freezing-point method is

$$M = \frac{C \times S}{S' \times \Delta},$$

where M is the molecular weight, C the constant for the solvent, S the weight of solute, S′ the weight of solvent, and △ the depression of the freezing-point. It is evident that if △ is very small

M is very large. A determination of the molecular weight of starch in this way gave results which indicate that the molecular weight of the carbohydrate is 32,400. This value corresponds to such a small lowering of the freezing-point that it can not be considered trustworthy, as the presence of a trace of impurity would have an effect on the result. The result indicates, however, that starch must have a very large molecular weight. Similar results have been obtained with other colloids.

304. Starch, $(C_6H_{10}O_5)_x$, occurs in nearly all plants, being present in large proportion in certain roots and seeds. It is manufactured from corn, wheat, potatoes, arrowroot, rice, and certain varieties of palm trees. It is present in the plant as granules, the form and size of which vary with the plant. It is possible in most cases to determine the source of a sample of starch by a microscopic examination.

In the United States the chief sources of starch are corn and wheat; in Europe potatoes, rice, and wheat are used. Corn contains about 54 per cent of starch, while potatoes yield about 15 per cent of their weight of the carbohydrate. The separation of starch from the other substances present in the grain or tuber, is accomplished largely by physical means: grinding, washing with water, and so forth. When corn is used it is steeped in warm water for a number of days. During this time much of the oil is removed, and the gluten and albuminous matter soften as the result of fermentation. The grain, mixed with water, is next ground in roller-mills. The product is then passed over bolting-cloth, through which the finely divided starch passes. The starch is washed with sodium hydroxide, stirred with water, and then allowed to settle. When the gluten, which deposits first, has settled, the supernatant liquid containing the starch in suspension is drawn off. Repetition of this process yields a product free from impurities. The starch as finally dried contains about 12 per cent of water.

Starch is extensively used as food, for laundry work, and in the preparation of glucose. The lower grades of starch are used in the textile industries for finishing cotton cloth. For this purpose rice starch is preferred. The starches obtained from different sources have slightly different properties. That obtained from wheat is used in making paste on account of its marked adhesive property. Sago, which is chiefly used as food, is a starch prepared from the pith of several varieties of palm trees; it swells in hot water without losing its globular form. Arrowroot starch is used for food and for laundry work and sizing purposes; it forms an unusually stiff jelly. Tapioca is prepared from cassava starch, which is obtained from the root of several plants which grow in tropical countries. It is made by stirring the moist hot starch until the granules burst and adhere together in irregular shaped, translucent kernels. The starch which is generally used in toilet-powders is that obtained from rice.

When starch is heated with water the granules swell and form a gelatinous mass as the result of the bursting of the membrane of cellulose which envelopes the granules; on longer heating a small amount of starch passes into solution. When treated with cold hydrochloric acid for a number of days, starch is changed into a variety which is soluble in water. At 200°–250° starch is changed into dextrin; at a higher temperature it chars. Starch does not reduce Fehling's solution, does not react with phenylhydrazine, and is not fermentable. It is readily hydrolyzed by acids and enzymes. *Diastase* and *ptyalin*, which is the characteristic enzyme of saliva, convert starch into maltose and dextrin. It is changed into dextrin, maltose, and glucose when heated with dilute acids. The proportion of the products of hydrolysis formed is determined by the conditions. The final product is glucose.

Starch gives a characteristic blue color with iodine; the test is more delicate in the presence of an iodide. The nature of the compound has not been definitely established.

Starch is determined quantitatively by converting it into glucose and determining the latter by means of Fehling's solution or optical analysis.

305. Dextrin is made by heating starch to 200°–250°. The product prepared in this way has a light brown color. A lighter colored dextrin is obtained by heating to 140°–170° starch which has been moistened with nitric or hydrochloric acid and dried at 50°. The formula of dextrin has not been definitely established; there is some evidence, however, in favor of the formula $C_{31}H_{62}O_{31}$. It is probable that a number of dextrins exist.

Dextrin dissolves in cold water and forms a thick syrup, which has strong adhesive properties. It is used for thickening colors in calico-printing, and in making the mucilage which is used on postage stamps. Dextrin syrups are also employed in brewing, for thickening tanning extracts, and in confectionery.

Dextrin is dextrorotatory, $[\alpha]_D = 196°$; it forms a phenylhydrazone, reduces Fehling's solution, and gives a yellow color with alkalies. It, therefore, contains a free carbonyl group. Dextrin gives with a solution of iodine a color which varies from violet to red.

306. Glycogen, $(C_6H_{10}O_5)_x$, is a carbohydrate, chiefly of animal origin, which resembles starch in some of its properties. It occurs in the liver, and in smaller proportion in the blood, spleen, kidneys, pancreas, and brain. It is found in a large number of fungi, where it seems to take the place of starch in higher plants. It also occurs in scallops and in certain insects. Glycogen is a white amorphous powder, which forms an opalescent solution with water. It is strongly dextrorotatory, the specific rotation varying with the concentration. An aqueous solution of glycogen gives a red color with iodine. It does not reduce Fehling's solution. *Diastase* and the *ptyalin* of saliva convert glycogen into maltose, glucose, and a dextrin. Acids hydrolyze it to dextrose. Glycogen does not ferment with yeast.

307. Inulin, $(C_6H_{10}O_5)_x$, is a starch-like substance which occurs in the roots of the dandelion and chicory, in the tubers of the potato and dahlia, in certain lichens, and in other vegetable substances. Inulin is a white powder, composed of minute spheres; it is slightly soluble in cold water, and very soluble in hot water. An aqueous solution of inulin does not form a jelly, is not colored by iodine, is not fermentable, and is not affected by diastase. It is levorotatory, $[\alpha]_D = -36.6°$.

Inulin is slowly converted into levulose when boiled with water; the rate of transformation is greatly increased by the presence of an acid.

308. Cellulose, $(C_6H_{10}O_5)_x$, constitutes the frame work of the vegetable kingdom. It occurs in nearly pure condition in certain plants, and probably in combination with other substances in the various kinds of wood. It can be separated from the compounds with which it is associated by treatment with various reagents. Cellulose is a comparatively stable substance, and is insoluble in all simple solvents. It can be obtained by treating woody fiber, jute, flax, and so forth, successively, with chlorine and sodium hydroxide. A number of such treatments convert the substances present with the cellulose into soluble compounds. Cotton-wool, which is comparatively pure cellulose, may be freed from impurities by extraction with alcohol, ether, and dilute acids and alkalies. The so-called washed filter paper is almost pure cellulose.

Cellulose dissolves in Schweitzer's reagent, which is prepared by dissolving carefully washed precipitated copper hydroxide in ammonia. From this solution it is precipitated in an amorphous condition by acids and salts. Advantage is taken of the effect of this reagent on cellulose in the preparation of waterproof paper. A sheet of paper left for a short time in contact with Schweitzer's reagent is superficially attacked, and when passed through rollers and dried is rendered impervious to water.

Cellulose dissolves in concentrated sulphuric acid; when the solution is diluted with water and boiled, soluble carbohydrates are formed, which vary in complexity from soluble celluloses and dextrins to dextrose, the final product of hydrolysis. When unsized paper is left in contact for a moment with sulphuric acid diluted with about one-fourth its volume of water, the surface of the paper is converted into a colloidal modification of cellulose called *amyloid*. After washing in water and dilute ammonia the paper is found to have a smooth surface, and to have been markedly toughened by the treatment. The so-called parchment paper is prepared in this way. Amyloid is colored blue by iodine; the reaction is used as a test for cellulose.

Dilute solutions of the alkalies do not appreciably affect cellulose. With strong solutions, however, compounds with the alkali are formed, which decompose with water to form a hydrate of cellulose. These chemical changes are associated with a marked alteration in physical properties in the case of cellulose which is in the form of fibres. These changes take place in the manufacture of "mercerized cotton." When cotton yarn is treated with a solution of sodium hydroxide which has the specific gravity 1.25, the fiber becomes rounded, swollen, and semi-transparent, the interior cavity of the fiber almost disappears, and the yarn shrinks. The resulting product has a high luster and silky appearance. In mercerizing cotton the yarn or cloth is held under tension in order to prevent shrinking during the treatment with alkali and the subsequent washing. As the result of mercerization cotton increases in weight on account of the change of cellulose to a hydrate, and can be dyed more readily.

309. The presence of alcoholic hydroxyl groups in cellulose is shown by its behavior with reagents which react with such groups. When treated with acetic anhydride in the presence of a trace of concentrated sulphuric acid, cellulose is converted into a triacetate, $C_6H_7O_5(OC.CH_3)_3$, which finds important industrial application. Cellulose acetate is deposited from solution in the form of a tough film when the solvent evaporates; such films are used in photography, as an insulating coating for copper wire, and for other purposes.

Cellulose reacts with nitric acid to form nitrates, which are commonly called nitrocellulose. The number of acid radicals introduced is determined by the strength of acid used, the time during which the reacting substances are allowed to remain in contact, and the temperature. If cotton is treated with a mixture of concentrated nitric acid and concentrated sulphuric acid the hexanitrate $[C_{12}H_{14}O_4(NO_3)_6]_x$, is formed. The substance is called a hexanitrate and is considered as derived from a complex containing twelve carbon atoms, on account of the fact that a pentanitrate, $[C_{12}H_{15}O_5(NO_3)_5]_x$, is known.

Cellulose hexanitrate, called *gun-cotton,* is used in making smokeless powder. It is insoluble in water, alcohol, ether, and chloroform. It resembles in texture the cotton from which it is made. In the preparation of the explosive the nitrated cotton is converted into a pulp and moulded into the desired shape by pressure. When exploded, gun-cotton is converted into carbon dioxide, carbon monoxide, nitrogen, hydrogen, and water vapor.

The lower nitrates of cellulose are called *pyroxylin;* they are formed by replacing hydroxyl groups by two, three, four, or five nitric acid radicals in the complex $C_{12}H_{20}H_{10}$. Those containing the smaller percentage of nitrogen are soluble in a mixture of alcohol and ether, the solubility decreasing with increase in the proportion of nitrogen present. *Collodion* is a solution of pyroxylin in alcohol and ether. *Celluloid* is prepared by intimately mixing about two parts of pyroxylin with one part of camphor.

310. *Wood* contains in addition to cellulose a substance called *lignin*, the composition of which has not been definitely established. It probably exists in wood in combination with cellulose as a compound which is called lignocellulose. A number of lignocelluloses exist in different varieties of wood. The reactions of these substances indicate that the lignin which is present contains a free aldehyde group, as they reduce solutions of the oxide of copper and certain other metals. Lignin reacts with chlorine, caustic alkalies, bisulphites of the alkaline earths, and sulphur dioxide to form compounds which are soluble in water.

These facts are made use of in the manufacture of *paper* from wood. In the process, the wood, which has been cut into small chips, is digested under pressure with a solution of sodium hydroxide, or calcium sulphite. This treatment frees the cellulose from lignin, resins, and other substances, and converts it into a pulp which, after disintegration and washing, is made into paper. This is done by passing a thin layer of the pulp through rolls, which squeeze out the water and convert the pulp into a compact sheet.

The presence of lignin in wood, straw, bran, and so forth, can be shown by certain characteristic color reactions. Such substances give a yellow color when treated with aniline hydrochloride, and a crimson color with phloroglucinol and hydrochloric acid. Lignin belongs to the class of compounds known as *pentosans*. They are so-called because they yield a pentose on hydrolysis.

Wood contains from 8 to 10 per cent of a gum which is a mixture of complex carbohydrates. Wood gum yields xylose on hydrolysis and, like other substances which contain pentosans, is converted into furfural on boiling with hydrochloric acid. The formation of furfural, it will be recalled, is a test for a pentose (**295**).

311. The cellular tissue of many fruits contains cellulose associated with other substances of the nature of carbohydrates. Apples, pears, and other fruits contain a substance called pectocellulose, which is probably a chemical compound of cellulose and pectin, as it gives cellulose and pectic acid on hydrolysis with an alkali. Pectin, which is a complex carbohydrate present in certain fruits, is converted into pectic acid when heated with a solution of an alkali. The formation of jellies from fruits is brought about as the result of the hydrolysis of the pectin which they contain. The hydrolysis converts pectin into pectic acid, which forms calcium pectate with the calcium salts always found in the fruit. Pectic acid and calcium pectate set to a jelly when certain fruits are boiled with water, and the juice is expressed and allowed to cool. On longer boiling with water or a solution of an acid, pectic acid is converted into parapectic acid, metapectic acid, and finally into pectinose which is identical with arabinose. On account of the transformations which pectic acid undergoes, fruit juices which contain acids lose the property of forming a jelly if heated for too long a time.

312. Gums. — The name gum is given to more or less complicated substances, most of which are mixtures, which contain carbohydrates, and make sticky liquids when mixed with water. On hydrolysis the gums yield a pentose or hexose. *Arabin* (arabic acid) occurs in nature as a mixture of the calcium, magnesium, and potassium salts in gum arabic. It is converted into arabinose on hydrolysis. *Agar-Agar* is obtained in China from seaweed. It is a gum which gives galactose on hydrolysis. *Xylan* is a wood gum which is found in the bark of trees. It can be obtained by extracting pine-wood sawdust or straw with dilute sodium hydroxide, and precipitating the alkaline solution with alcohol and hydrochloric acid. Xylan is a porous mass which dissolves in hot water to form a solution that becomes opalescent on cooling. It yields xylose when hydrolyzed by acids; when distilled with acids, the xylose formed is converted into furfural.

313. Identification of Carbohydrates. — All carbohydrates give a marked color when treated with α-napthol (**448**) and concentrated sulphuric acid (Molisch carbohydrate reaction). The test is carried out by treating about 5 milligrams of the substance with 10 drops of water and 2 drops of a 10 per cent solution of α-napthol in chloroform; about 1 cc. of pure concentrated sulphuric acid is then added to the mixture carefully so that two layers are formed. If a carbohydrate is present, a red ring will appear in a few seconds; on longer standing, or on shaking, a deep purple color will develop. When the solution is diluted with water, a dull violet precipitate is formed, which is changed to a yellowish brown color when treated with ammonia. As certain substances other than carbohydrates give colorations when treated with concentrated sulphuric acid, and as certain acids act like carbohydrates in the Molisch reaction, it is necessary to make additional tests in case a substance responds to the reaction in the manner indicated. If the compound studied proves to be an acid when tested with litmus, or if it gives the characteristic color changes when treated with concentrated sulphuric acid alone, it is not a carbohydrate.

In identifying individual members of the class of carbohydrates, the osazones are usually prepared. Most carbohydrates do not melt sharply, as they undergo more or less decomposition when heated to their melting-points. The action of a carbohydrate with Fehling's solution is also helpful in its identification.

Pentoses are distinguished by their action when boiled with phloroglucinol and hydrochloric acid; arabinose and xylose produce a bright red color, which deepens in shade as the solution is boiled. Certain hexoses or polyoses give an orange color when heated with phloroglucinol and hydrochloric acid.

The soluble carbohydrates are most readily identified, in most cases, by determining their specific rotation.

PROBLEMS

1. Tabulate the following properties of the carbohydrates described in the text: solubility in water, products formed on hydrolysis, fermentability, action with Fehling's solution, and action with phenylhydrazine.

2. Write equations, using graphic formulas, for the reactions by which (*a*) levulose may be converted into dextrose, (*b*) arabinose into an aldohexose, (*c*) xylose into a ketohexose, and (*d*) allyl alcohol into a tetrose.

3. Outline a method of determining the amount of each carbohydrate in a mixture of glucose, starch, and cellulose.

CHAPTER XVI

COMPOUNDS CONTAINING PHOSPHORUS, ARSENIC, SULPHUR, METALS

314. Phosphorus occurs in a large number of natural products of complex composition. It is an important constituent of certain proteins, which will be described later, and of the lecithins (**174**). Many of these compounds are esters of phosphoric acid in which the alcohol in combination with the acid is glycerol or a carbohydrate.

Many simple compounds of phosphorus are known, but they do not warrant detailed description here. *Esters of phosphoric acid and phosphorous acid* are formed when the halides of phosphorus are treated with an alcohol. It has already been pointed out that the interaction of these substances yields alkyl halides, a number of reactions taking place simultaneously. Typical reactions are those which take place between alcohol and phosphorus tribromide: —

$$3C_2H_5OH + PBr_3 = 3C_2H_5Br + P(OH)_3$$
$$3C_2H_5OH + PBr_3 = 3HBr + P(OC_2H_5)_3$$

Under certain conditions compounds are obtained which contain halogen, such as $PBr_2(OC_2H_5)$. Esters can also be made by the action of the silver salts of the acids on alkyl iodides. Monoethyl phosphate can be prepared by treating alcohol with phosphoric acid; it is often called ethyl phosphoric acid: —

$$C_2H_5OH + H_3PO_4 = C_2H_5.H_2PO_4 + H_2O$$

The *phosphines* are compounds which are formed as the result of the replacement of one or more hydrogen atoms in phosphine, PH_3, by alkyl radicals. They resemble the amines in composition, and the methods employed to prepare them are, in general, analogous to those already described in the case of the derivatives of ammonia. The phosphines react with water to form bases, which are weaker than the analogous ammonium compounds. Tetraethylphosphonium hydroxide, $(C_2H_5)_4P.OH$, is, however, a strong base.

The noticeable differences in chemical properties between the phosphines and amines, are due to certain marked differences between nitrogen and phosphorus. The action of oxygen on the two elements furnishes a striking case; nitrogen and many of its compounds are inert, while phosphorus and certain of its derivatives are readily oxidized. This marked difference in activity between the two elements is met with in certain of their organic derivatives. Triethylamine, for example, is stable in the air, whereas triethylphosphine rapidly absorbs oxygen and forms an oxide, $(C_2H_5)_3PO$. Some phosphines oxidize so rapidly that they are spontaneously inflammable.

315. Arsenic forms primary, secondary, and tertiary arsines, and quarternary bases. Tertraethylarsonium hydroxide, $(C_2H_5)_4As.OH$, is a base, which forms well characterized salts. *Cacodyl* and its derivatives are arsenic compounds which had a marked influence on the development of the theories of organic chemistry. The compounds were investigated by Bunsen, who prepared cacodyl oxide, $[(CH_3)_2As]_2O$, by distilling arsenous oxide with potassium acetate. From the oxide, the chloride, $(CH_3)_2AsCl$, was formed by the action of hydrochloric acid; the chloride yielded cacodyl, $[(CH_3)_2As]_2$, when treated with zinc. Other compounds such as the bromide, cyanide, and so forth, were prepared. All these contain the group $(CH_3)_2As$. It appeared from the results obtained by Bunsen and the investigations by Gay-Lussac on cyanogen, and Liebig and Wöhler on benzoyl derivatives, that groups of atoms could pass intact from one compound to another. To such groups the name "radical" was applied. The first attempts to elucidate the structure of organic compounds were directed toward the discovery of the radicals which they contained.

Compounds Containing Sulphur

316. Many compounds of sulphur, which may be divided into a number of classes, are known. As sulphur resembles oxygen in many of its chemical properties, we might expect to have a series of organic compounds containing sulphur analogous in composition to the oxygen derivatives of the hydrocarbons which have been described. A large number of such compounds are known, but only a few will be described here. The marked differences between sulphur and oxygen must be borne in mind in the study of the sulphur compounds. It will be remembered that sulphur is a more negative element than oxygen; the compound of oxygen and hydrogen, H_2O, is neutral, the analogous compound of sulphur, H_2S, is an acid. Further, sulphur forms well characterized compounds in which the element exhibits valences of four and six, while oxygen is bivalent; hydrogen sulphide can be oxidized to sulphuric acid. These striking differences between oxygen and sulphur lead to reactions in the case of organic compounds containing sulphur, which are not shown by the analogous oxygen derivatives.

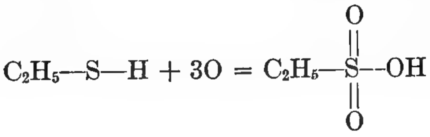
317. Mercaptans may be considered as monosubstitution-products of hydrogen sulphide, $C_2H_5.SH$, just as the alcohols are considered as derivatives of water, $C_2H_5.OH$. They are sometimes called thio-alcohols. The name mercaptan was originally given to the members of this class on account of the fact that they form compounds with mercury. The name is derived from the Latin words *mercurium captans*. Ethyl mercaptan is a typical member of the class. It is prepared by methods which are analogous to those used in making alcohols: —

$$C_2H_5Br + KSH = C_2H_5SH + KBr$$
$$C_2H_5SO_4K + KSH = C_2H_5SH + K_2SO_4$$

It is a liquid which has an excessively disagreeable odor. It is said that it is possible to detect about 0.000000002 milligram of the substance. Ethyl mercaptan boils at 36°, and is difficultly soluble in water.

The hydrogen joined to sulphur in mercaptan can be replaced by metals; the compounds so formed are more stable than the alcoholates. The mercury compound has the formula $(C_2H_5S)_2Hg$.

Mercaptans can be oxidized readily on account of the possibility of increasing the valence of the sulphur atom present. The resulting compounds are called sulphonic acids: —



$$C_2H_5{-}S{-}H + 3O = C_2H_5{-}\underset{\underset{\displaystyle O}{\|}}{\overset{\overset{\displaystyle O}{\|}}{S}}{-}OH$$

318. **Sulphides** or thioethers are disubstitution-products of hydrogen sulphide. They can be prepared by treating an alkyl halide or a salt of an alkyl sulphuric acid with potassium sulphide: —

$$2C_2H_5I + K_2S = (C_2H_5)_2S + 2KI$$
$$2C_2H_5SO_4K + K_2S = (C_2H_5)_2S + 2K_2SO_4$$

They are formed also by the action of a sodium salt of a mercaptan in an alkyl iodide: —

$$C_2H_5I + C_2H_5SNa = (C_2H_5)_2S + NaI$$

The method last given is analogous to an important one used to prepare ethers. The sulphides are liquids, most of which have a very disagreeable odor. Allyl sulphide, $(CH_2{=}CH.CH_2)_2S$, is the chief constituent of the *oil of garlic.*

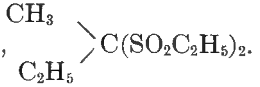
Like the mercaptans, the sulphides are readily oxidized. Nitric acid converts ethyl sulphide into *ethyl sulphoxide*, $(C_2H_5)_2SO$, which on more energetic oxidation yields a *sulphone*, $(C_2H_5)_2SO_2$.

Sulphonal, which is used as a soporific, is a disulphone derived from mercaptan. When a mixture of acetone and mercaptan is treated with hydrochloric acid, condensation takes place according to the equation, —

$$(CH_3)_2CO + 2C_2H_5SH = (CH_3)_2C(SC_2H_5)_2 + H_2O$$

The substance so formed yields on oxidation a disulphone, which is sulphonal: —

$$(CH_3)_2C(SC_2H_5)_2 + 4O = (CH_3)_2C(SO_2C_2H_5)_2$$

Trional is made in an analogous manner from methyl ethyl ketone; it has the structure,  $\begin{matrix}CH_3\\C_2H_5\end{matrix}\!\!>\!C(SO_2C_2H_5)_2$. *Tetronal*, which has a similar constitution, contains four ethyl groups.

319. The sulphides unite with alkyl iodides to form salts of the *sulphonium bases*: —

$$(C_2H_5)_2S + C_2H_5I = (C_2H_5)_3S.I$$

The reaction is analogous to that by which salts of the ammonium bases are formed: —

$$(C_2H_5)_3N + C_2H_5I = (C_2H_5)_4N.I$$

Like these, the sulphonium salts are converted into bases when shaken in aqueous solution with silver oxide: —

$$(C_2H_5)_3SI + AgOH = (C_2H_5)_3S.OH + AgI$$

Triethylsulphonium hydroxide is a strong base; it absorbs carbon dioxide from the air and forms crystalline salts with acids.

320. Thioacids can be prepared by the action of potassium hydrosulphide on acid chlorides: —

$$CH_3COCl + KSH = CH_3COSH + KCl$$

or by distilling acetic acid with phosphorus pentasulphide. These two ways of preparing thioacetic acid are illustrations of two general methods used in the synthesis of sulphur compounds. That in which potassium hydrosulphide is used is analogous to the method of preparing hydroxyl compounds by the use of potassium hydroxide: —

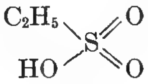
$$CH_3COCl + KOH = CH_3COOH + KCl$$
$$CH_3COCl + KSH = CH_3COSH + KCl$$
$$C_2H_5Br + KOH = C_2H_5SH + KBr$$
$$C_2H_5Br + KSH = C_2H_5SH + KBr$$

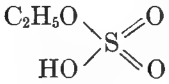
The action of phosphorus pentasulphide on oxygen compounds generally brings about the replacement of oxygen by sulphur; acetic acid gives thioacetic acid, alcohol gives mercaptan, and ether gives ethyl sulphide. In all cases the oxygen enters into combination with phosphorus.

The thioacids are liquids which have a disagreeable odor. The salts of these acids which contain a heavy metal are decomposed when heated in aqueous solution, and sulphides of the metals are precipitated.

321. Thioaldehydes and **thioketones** are not known in the pure condition. When hydrogen sulphide is passed into an aqueous solution of aldehyde, an oil is formed which appears to be a mixture of thioaldehyde and its polymer $(CH_3.CHS)_3$. When acetone is treated in the same way, thioacetone, $CH_3.CS.CH_3$, is probably formed along with other substances.

322. Sulphonic acids are compounds which contain the SO_3H group, in which the organic radical present is in combination with sulphur. The relation between the structure of ethanesulphonic acid and acid ethyl sulphate is shown by the formulas, —


sulphonic acid


acid sulphate

It has already been stated that the higher paraffins are converted in part into sulphonic acids when boiled with concentrated sulphuric acid for a number of days. The reaction between the acid and a hydrocarbon involves the elimination of water: —

$$C_7H_{16} + H_2SO_4 = C_7H_{15}SO_3H + H_2O$$

As this method is not a practical one, the sulphonic acids are usually prepared by the action of sulphites on alkyl halides: —

$$C_2H_5I + K_2SO_3 = C_2H_5SO_3K + KI$$

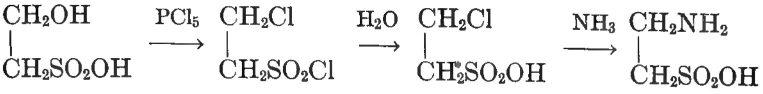
While the saturated hydrocarbons are but slowly affected by sulphuric acid or sulphur trioxide, their derivatives react more energetically with these reagents. When alcohol, for example, is treated with sulphur trioxide, sulphonation takes place, that is, the alcohol is converted into a sulphonic acid: —

$$CH_3.CH_2OH + SO_3 = HSO_3CH_2.CH_2OH$$

The compound formed is β-hydroxy-ethanesulphonic acid; it is usually called *isethionic acid. Ethionic acid*, which is the acid sulphate of isethionic acid, $HSO_3.CH_2.CH_2.SO_4H$, is formed at the same time. Both acids are formed in small quantity in the preparation of ether from alcohol and sulphuric acid.

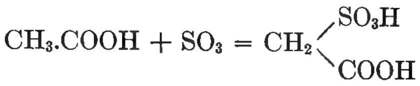
323. Taurine, β-amino-ethane-sulphonic acid, is found in combination with other substances in the bile of many animals.

It can be prepared from isethionic acid by the steps indicated by the following formulas: —



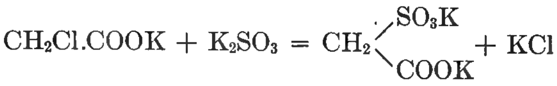
$$\begin{array}{l} CH_2OH \\ | \\ CH_2SO_2OH \end{array} \xrightarrow{PCl_5} \begin{array}{l} CH_2Cl \\ | \\ CH_2SO_2Cl \end{array} \xrightarrow{H_2O} \begin{array}{l} CH_2Cl \\ | \\ CH_2SO_2OH \end{array} \xrightarrow{NH_3} \begin{array}{l} CH_2NH_2 \\ | \\ CH_2SO_2OH \end{array}$$

Sulphoacetic Acid. — Acetic acid can be sulphonated: —



$$CH_3.COOH + SO_3 = CH_2\begin{array}{l} \diagup SO_3H \\ \diagdown COOH \end{array}$$

The acid can also be prepared from chloracetic acid and potassium sulphite: —



$$CH_2Cl.COOK + K_2SO_3 = CH_2\begin{array}{l} \diagup SO_3K \\ \diagdown COOK \end{array} + KCl$$

324. Thiocyanic acid, HCNS, often called sulphocyanic acid, resembles cyanic acid in properties. It can be obtained as a volatile, pungent liquid, which rapidly polymerizes to a solid. *Potassium thiocyanate* is formed by heating a solution of potassium cyanide with sulphur: —

$$KCN + S = KCNS$$

Ferric thiocyanate, $Fe(CNS)_3$, has a characteristic blood-red color; it is formed when a soluble thiocyanate is added to a ferric salt. The reaction furnishes a convenient test for ferric salts or a thiocyanate. The so-called "Pharaoh's serpents" are made from *mercuric thiocyanate*. *Ammonium thiocyanate*, NH_4CNS, is converted by heat into *thiourea*, $SC(NH_2)_2$, the reactions of which are analogous to those of urea, $CO(NH_2)$.

Esters of thiocyanic acid are obtained by the action of alkyl iodides on the salts of the acid: —

$$KSCN + C_2H_5I = C_2H_5SCN + KI$$

As these esters yield mercaptans on reduction, it is assumed that the alkyl radicals which they contain are linked to sulphur, $C_2H_5 - S - C \equiv N$.

When heated, the alkyl thiocyanates are changed into the isomeric *isothiocyanates*: —

$$R—S—C \equiv N \rightarrow R—N = C = S$$

The esters of this structure are also called *mustard oils*, after *allyl isothiocyanate*, $CH_2=CH.CH_2.NCS$, the constituent of mustard which gives it its characteristic odor and taste. The radicals in isothiocyanates are considered to be joined to nitrogen on account of the fact that these esters yield amines on hydrolysis.

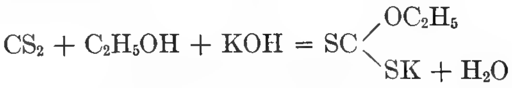
325. The **alkyl thiocarbonates** are derived from dithiocarbonic acid, HO.CS.SH, or trithiocarbonic acid, HS.CS.SH. Carbon disulphide reacts with sulphides to form salts analogous to the carbonates, which are formed by the union of carbon dioxide and metallic oxides: —

$$CS_2 + CaS = CaCS_3$$
$$CO_2 + CaO = CaCO_3$$

Esters of trithiocarbonic acid are formed from inorganic salts of the acid in the usual way: —

$$K_2CS_3 + 2CH_3SO_4K = (CH_3)_2CS_3 + 2K_2SO_4$$

The more important thioderivatives of carbonic acid are those which contain two sulphur atoms. The salts of the *xanthic acids* are formed by shaking together carbon disulphide, an alcohol, and an alkali. Potassium xanthate is prepared in this way from alcohol: —



$$CS_2 + C_2H_5OH + KOH = SC\begin{cases} OC_2H_5 \\ SK \end{cases} + H_2O$$

Traces of carbon disulphide are detected by means of this reaction. The potassium xanthate formed produces a characteristic yellow precipitate when treated with a solution of a copper salt.

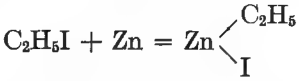
When cellulose is treated with carbon disulphide and sodium hydroxide, a cellulose xanthate is formed. This salt when stirred with a small amount of water forms a thick solution, called *viscose*, which is converted into cellulose hydrate by heat or certain salts. By squirting viscose through capillary tubes into a solution which brings about this decomposition, threads of cellulose are obtained having a silky luster. From these artificial silk is made. Viscose is also used for paper-sizing, in textile printing, and as a cement.

Organo-metallic Compounds

326. Many elements form compounds in which alkyl groups are in combination with the element. The amines NR_3, phosphines PR_3, sulphides SR_2, ethers OR_2 have already been described. Compounds of this type which contain the metallic elements, such as zinc, tin, lead, aluminium, mercury, and so forth, have been prepared. They are known as organo-metallic compounds or as metallic alkides. They were first described by Frankland, who pointed out clearly in 1852 that the metals and other elements differed from one another in their ability to hold in combination organic radicals; some could unite with two radicals, some with three, and some with four. From these facts he was led to propose the doctrine of valency. The organo-metallic compounds have been of great service in determining the valence of metals on account of the fact that they may be vaporized without decomposition. The student will recall the fact that the molecular weight, and, consequently, the formula of a compound, can be calculated from its percentage composition and the density of its vapor.

On account of their value in synthetic organic chemistry, certain metallic alkides which contain zinc and magnesium will be described briefly.

Zinc ethyl, $Zn(C_2H_5)_2$, is prepared from zinc and ethyl iodide. When the two substances are heated together addition takes place slowly: —



$$C_2H_5I + Zn = Zn\begin{matrix} \diagup C_2H_5 \\ \diagdown I \end{matrix}$$

The reaction takes place more rapidly in the presence of a small quantity of ethyl acetate or methyl cyanide, or when the zinc-copper couple is used. Zinc ethyl iodide is a colorless, crystalline solid, which is decomposed by water, and reacts with many compounds that contain a halogen or oxygen. The decomposition in the case of water is represented by the equation, —

$$C_2H_5.Zn.I + HOH = C_2H_6 + Zn.OH.I$$

When heated, zinc ethyl iodide decomposes, and zinc ethyl is formed: —

$$2C_2H_5.Zn.I = Zn(C_2H_5)_2 + ZnI_2$$

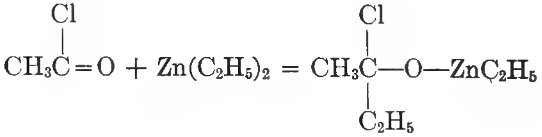
Zinc ethyl is a colorless liquid, which boils at 118°, and fumes in the air. It takes fire spontaneously, and burns with a luminous green-edged flame.

The zinc alkides were formerly much used in effecting syntheses, but they have been recently replaced for this purpose by the more stable alkyl derivatives of magnesium, which can be prepared more readily. A few typical reactions into which zinc ethyl enters are expressed by the following equations: —

$$Zn(C_2H_5)_2 + 2HOH = Zn(OH)_2 + 2C_2H_6$$
$$Zn(C_2H_5)_2 + 2C_2H_5I = ZnI_2 + 2C_2H_5.C_2H_5$$
$$Zn(C_2H_5)_2 + HgCl_2 = ZnCl_2 + Hg(C_2H_5)_2$$

Zinc ethyl forms addition-products with acid chlorides which yield ketones on decomposition with water. In this way, methyl ethyl ketone, $CH_3.CO.C_2H_5$, may be prepared from acetyl chloride, $CH_3.COCl$, and ethyl iodide. In this transformation and the last two reactions given above, a halogen atom is replaced by an alkyl group. Zinc alkides bring about, in most cases, the replacement of halogen by alkyl.

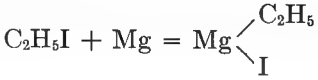
Zinc alkides form addition-products with aldehydes and ketones, which on treatment with water, yield secondary and tertiary alcohols, respectively. In the reactions between organo-metallic compounds and substances which contain the carbonyl group (C = O), the positive, metallic atom enters into combination with the negative oxygen atom, and the alkyl radical unites with carbon. The structure of the compound formed from zinc ethyl and acetyl chloride is an example: —



$$CH_3\overset{\overset{Cl}{|}}{C}=O + Zn(C_2H_5)_2 = CH_3\underset{\underset{C_2H_5}{|}}{\overset{\overset{Cl}{|}}{C}}—O—ZnC_2H_5$$

This addition-product yields on decomposition with water, methyl ethyl ketone, zinc hydroxide, and ethane.

327. Magnesium compounds which contain alkyl radicals can be readily prepared by the action of the metal on alkyl halides:—



$$C_2H_5I + Mg = Mg\begin{array}{l}\diagup C_2H_5\\ \diagdown I\end{array}$$

The reaction is usually brought about by adding magnesium in the form of powder or ribbon to a solution of the alkyl halide in dry ether. Reaction takes place more promptly if a trace of iodine is added to the mixture. The magnesium alkyl halides so prepared are solids, which are soluble in ether. The solutions formed in the way indicated are much used in effecting the preparation of compounds of various classes. The applications of magnesium alkyl halides to the preparation of hydrocarbons (**17**), secondary alcohols and tertiary alcohols (**66**), and ketones (**157**), have been described.

PROBLEM

1. Write equations, using graphic formulas, for reactions by which the following may be prepared by means of the Grignard reaction: (*a*) $CH_3CH_2CH(CH_3)_2$, (*b*) $C_3H_7.CH_3.CHOH$, (*c*) $CH_3.C_2H_5.C_3H_7.COH$, (*d*) $CH_3COC_4H_9$.

CHAPTER XVII

THE IDENTIFICATION OF ORGANIC COMPOUNDS AND THE DETERMINATION OF THEIR STRUCTURE

328. As the different classes of organic compounds have been described in previous chapters, emphasis has been placed upon those reactions of the various substances which are of particular value in identifying the characteristic groups that they contain. The reactions which take place between oxygen compounds and phosphorus pentachloride, for example, have been described in detail, and it has been pointed out that the composition of the products formed gives, in most cases, definite information as to the way in which the oxygen is linked to other atoms in the molecule. By means of this reagent it is possible to determine whether the oxygen compound is an ether, ketone, or hydroxyl derivative. A number of qualitative tests have also been described, such as those for carbohydrates, aldehydes, esters, and so forth. The plan of this chapter is to bring together these various tests and reactions, and show by a few examples how they may be used in identifying a substance which has already been described, and in determining the structure of new substances.

The student has already seen, in a number of cases, how the structure of a substance is derived from a study of its reactions. But in most of the cases which have been described, the structural formula has been given, and it has been shown that the reactions of the substance are in accord with the formula. It is easier to see the relations between structure and reactions from this point of view, and, consequently, this method has been adopted up to the present. In determining the structure of a new substance, the investigator has before him only the results of analyses and molecular weight determinations of the new compound and the derivatives which he has prepared from it.

From these data he arrives at the structural formula. An attempt will be made to show how such conclusions are reached.

The study of the transformations of organic compounds from this point of view is of the greatest importance. The study at this time furnishes a very practical review of many facts already presented, and gives the student an opportunity to use the facts which he has learned. The problems given at the end of the chapter should be solved, after the methods used in their solution, which are about to be described, have been studied. The student will in this way gain power in attacking organic problems, and will see more clearly the practical significance of the facts he has learned.

The reactions of the organic compounds treated up to this point, which are of particular value from the point of view of identification or the determination of structure, will be briefly reviewed. In the case of a number of classes certain of these reactions and tests have already been summarized. In such cases references to the sections in which the summaries are given will be stated, in order to avoid undue repetition. These references should be re-read at this time along with what is now given. The attempt will not be made to include all the classes which have been mentioned, nor to emphasize exceptions to the general reactions discussed. It is the opinion of the author that in the study of the elements of organic chemistry, the attention of the student should be directed to general principles, and that the consideration of anomalous reactions and exceptions to the principles should be left to the detailed study of the specialist.

329. *Unsaturated Compounds.* — Read the section on the identification of hydrocarbons of the ethylene series (**35**), and of compounds containing a triple bond (**43**). If a substance of unknown structure forms a compound by the direct addition of two halogen atoms, the conclusion can be drawn that it is an unsaturated compound. In most cases it can be assumed that the substance contains a double bond between two carbon atoms. Thus, if a substance of the composition C_3H_6O is converted by bromine into one of the composition $C_3H_6OBr_2$, it is probable that it contains a double bond. If four atoms of halogen are added, the compound contains either two double bonds or one triple bond. If the compound gives a metallic derivative with an ammoniacal solution of cuprous chloride, it contains a triple bond. If this test is negative, other means must be employed to determine the nature of the unsaturation, as metallic compounds are formed only by substances which contain the $\equiv$CH group. Oxidation is frequently used for this purpose, as unsaturated compounds generally break at the double or triple bond when oxidized. The study of the compounds formed on oxidation is often of material help in determining the structure of unsaturated compounds.

Hydrocarbons. — Read the section on the detection of the paraffins (**27**). In order to identify a substance as a hydrocarbon it is necessary to apply all the tests for oxygen compounds. If these yield negative results and no elements other than carbon and hydrogen are found to be present, the conclusion can be drawn that the compound is a hydrocarbon.

Acids. — Read the paragraph on the properties of acids of analytical significance (**97**). Acids (R.COOH) neutralize alkalies and liberate carbon dioxide from carbonates. In testing for an acid it is better to use a carbonate, as some esters are rapidly saponified by alkalies in the cold.

In determining the structure of an acid, the composition of its salt is often studied. Thus, if an acid of the composition $C_5H_{10}O_2$ yields the salt $C_5H_9O_2Na$, it contains one carboxyl group, as one hydrogen atom is replaced by one sodium atom; if the acid $C_4H_6O_6$ gives the salt $C_4H_4O_6Na_2$, it is dibasic, as two hydrogen atoms are replaced by two sodium atoms.

Phosphorus pentachloride replaces hydroxyl groups by chlorine. The action of this reagent on a substance of unknown structure is often studied. If a carboxyl group is present, the hydroxyl group which it contains is replaced by chlorine; the substance loses one hydrogen atom and one oxygen atom, and gains one chlorine atom. Thus if the compound $C_5H_{10}O_2$ is converted into the compound C_5H_9OCl, it is said to contain a hydroxyl group.

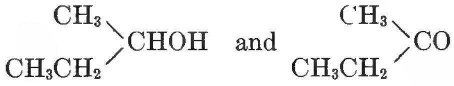
Alcohols. — Read the section on the reactions of alcohols (**67**). Alcohols react with acetyl chloride to form esters and hydrogen chloride, which is readily recognized by its fuming with moist air or with ammonia. Acetic anhydride also converts alcohols into esters, many of which have characteristic odors. Distillation of an alcohol with strong hydrobromic acid yields the corresponding bromide.

The presence of an alcoholic hydroxyl group is usually shown qualitatively by the application of the tests just described. The same reagents are employed in the quantitative study of alcohols. In the replacement of a hydrogen atom by an acetyl radical, CH_3CO, the compound loses one hydrogen and gains C_2H_3O. The ester differs in composition from the alcohol by C_2H_2O. Thus, if when the compound C_3H_8O is treated with acetyl chloride or acetic anhydride it is converted into one of the composition $C_5H_{10}O_2$, the conclusion is drawn that it contains one alcoholic hydroxyl group. If by the action of these reagents a substance of the formula $C_3H_8O_2$ yields one of the formula $C_7H_{12}O_4$, the former contains two such groups, as the ester differs in composition from the alcohol by $2(C_2H_2O)$.

The change in composition effected by the halides of phosphorus is the same as that described above under acids. For each hydroxyl group present there is a loss of one hydrogen and one oxygen, and a gain of one halogen atom.

Methods which can be used to determine qualitatively whether an alcohol is primary, secondary, or tertiary are described in the section on tertiary alcohols (**61**). In certain cases more complicated methods than those described must be used. The study of the products formed on oxidation gives definite information as to the nature of an alcohol. Oxidation of a primary alcohol, which contains the group CH_2OH, leads to the formation of an acid. In the change of CH_2OH to $COOH$, the compound loses two hydrogen atoms and gains one oxygen atom. If the compound $C_4H_{10}O$ yields the compound $C_4H_8O_2$ on oxidation, it contains a primary alcoholic group and the substances have the structural formulas $CH_3CH_2CH_2CH_2OH$, and $CH_3CH_2CH_2COOH$, respectively.

Ketones are formed from secondary alcohols by oxidation, the $CHOH$ group being converted into $C=O$. In this case the change consists in the removal of two hydrogen atoms. If a compound has, for example, the formula $C_4H_{10}O$ and its oxidation-product the formula C_4H_8O, the former is a secondary alcohol. The relation between the structures of the two substances in this case is shown by the formulas, —



Oxidation converts a tertiary alcohol into compounds which contain a smaller number of carbon atoms than the alcohol. It is clear from what has been said how the composition of the products of oxidation of an alcohol serves to determine its nature. If an alcohol of the formula $C_4H_{10}O$ gives a compound of the composition $C_4H_8O_2$ it is a primary alcohol; if the oxidation-product has the formula C_4H_8O, the alcohol is secondary; and if it yields two compounds, C_3H_6O and $C_2H_4O_2$, it has the tertiary structure.

Aldehydes. — The properties of aldehydes which are of special value in their identification are described in section **151.** Aldehydes on oxidation yield acids, the CHO group being converted into carboxyl, COOH. The aldehydes differ in composition from the acids by one oxygen atom. Phosphorus pentachloride replaces one oxygen atom by two chlorine atoms. Acid potassium sulphite adds directly to an aldehyde. Hydroxylamine forms oximes; the aldehyde, C_2H_4O, gives the oxime C_2H_5ON, the change in composition resulting in the addition of one hydrogen and one nitrogen atom to the molecule.

Ketones. — Read the section on the properties of ketones (**158**). Substances of this class show many of the reactions of aldehydes. They may be distinguished from the latter by an examination of the products formed on oxidation. The ketones are decomposed by oxidizing agents into substances containing a smaller number of carbon atoms.

Ethers. — The properties of ethers are described in section **110**. When an ether is heated with concentrated hydriodic acid, the alkyl groups linked to oxygen are converted into alkyl iodides. If a substance of the composition $C_{10}H_{22}O$ yields the iodide $C_5H_{11}I$ when boiled with hydriodic acid, the conclusion can be drawn that it contains a $C_5H_{11}O$ group.

Esters. — The methods for the qualitative identification of esters are described in section **139**. Esters yield on hydrolysis with sodium hydroxide an alcohol and the sodium salt of an acid. If the compound $C_8H_{16}O_2$ is converted by a solution of sodium hydroxide into the salt $C_5H_9O_2Na$ and the alcohol C_3H_8O, it can be concluded that it is a propyl ester of a valeric acid, C_4H_9COOH.

Anhydrides. — The important characteristic reaction of substances of this class are described in section **123**. Sodium hydroxide converts anhydrides into salts. Esters also yield salts, but with these compounds an alcohol is formed at the same time. If the compound $C_8H_{14}O_3$ is converted by sodium hydroxide into a salt of the composition $C_4H_7O_2Na$, it is evident that the original compound is the anhydride of the acid $C_3H_7.COOH$.

Amines. — The tests for amines and ammonium salts are given in section **170**. Amines form salts by direct addition to acids. If the substance C_3H_9N, for example, forms the compound $C_3H_{10}NCl$ it is probably an amine or a related basic compound such as a hydrazine, amidine, and so forth.

Amides. — Read the section on the identification of amides (**186**). In the conversion of an amide into a sodium salt of the corresponding acid, the amide loses one nitrogen and two hydrogen and gains one sodium and one oxygen atom. If a reaction takes place according to the equation, —

$$C_3H_7NO + NaOH = C_3H_5O_2Na + NH_3$$

it can be interpreted as follows: —

$$C_2H_5CONH_2 + NaOH = C_2H_5COONa + NH_3$$

In hydrolysis with acids the change in composition is brought about as the result of the loss of one hydrogen atom and one nitrogen atom, and a gain of one oxygen atom: —

$$C_3H_7NO + H_2O = C_3H_6O_2 + NH_3$$
$$C_2H_5CONH_2 + H_2O = C_2H_5COOH + NH_3$$

Esters of nitrous and nitric acids give alcohols and salts of these acids when hydrolyzed by a base.

Sulphur Compounds. — *Mercaptans* form salts by the replacement of one hydrogen atom by metals. *Sulphides* do not form salts: they yield sulphoxides and sulphones on oxidation. *Sul-*

phates of amines give a precipitate of barium sulphate with barium chloride. The alkyl sulphates yield inorganic sulphates on hydrolysis. The *sulphonic acids* are not hydrolyzed by bases.

Halogen Compounds. — The identification of *alkyl halides* is discussed in section **206**, and of *acyl halides* in section **223**. The halogen in both classes of compounds may be replaced by the hydroxyl group, the compound losing the halogen atom and gaining one hydrogen and one oxygen atom. If the substance of the composition C_4H_9Cl is converted into one of the composition $C_4H_{10}O$ when heated for a long time at a high temperature with water or a solution of potassium hydroxide, it can be concluded that the former is an alkyl halide. An analogous change takes place more rapidly at a low temperature in the case of acyl halides.

THE IDENTIFICATION OF UNKNOWN SUBSTANCES

330. A number of examples will now be given to illustrate how the principles outlined above may be used in identifying substances which have been previously described.

The substance to be identified must be in a pure condition in order that its physical properties may be accurately determined and the conclusions drawn from its reactions may be trustworthy. If the substance does not show the characteristics of a pure compound, it must be purified by the methods already outlined (**7**, **8**). A qualitative analysis is next made to determine what elements are present. The action of the compound is then studied with water, concentrated sulphuric acid, a hot and a cold solution of sodium hydroxide, dilute hydrochloric acid, acetyl chloride, bromine, sodium carbonate, phenylhydrazine, and Schiff's reagent. The carbohydrate test (**313**) should be applied, and if the compound contains sulphur the reactions given above under sulphur compounds should be studied. It is sometimes advisable and is often necessary to use other reactions than those just mentioned. A few examples will now be given.

I. (1) The substance contains nitrogen and sulphur.

(2) It is an odorless, colorless solid which is soluble in water.

(3) Sodium hydroxide precipitates an oil, which is soluble in dilute acids.

(4) Barium chloride gives a precipitate, insoluble in acids.

(5) The substance liberated by (3) does not react with acetyl chloride.

Observation (1) suggests the determination of the class of nitrogen compounds to which the substance belongs. Observation (2) indicates that it may be a salt of an amine — a conclusion confirmed by (3). These results, together with the fact that the compound contains sulphur, suggests test (4), which indicates a sulphate. The test applied to the oil obtained in (3) to determine the class to which the amine belongs (5), indicates that the original substance contains a tertiary amine. The study of the compound leads, then, to the conclusion that it is a sulphate of a tertiary amine. The identification is completed by the determination of physical properties. The boiling-point of the free amine was determined in this case to be 157°, and its specific gravity to be 0.76. An examination of the physical constants of the known tertiary amines showed that the values obtained in this case were those which have been found for tripropylamine. The compound identified is, therefore, the sulphate of tripropylamine.

II. (1) Qualitative analysis showed that no elements other than carbon, hydrogen, and oxygen were present.

(2) The substance liberated carbon dioxide from sodium carbonate.

(3) It reacted with acetyl chloride and hydrogen chloride was evolved.

(4) Tests for aldehydes, ketones, esters, anhydrides, and ethers gave negative results.

Observation (2) indicates that the substance is an acid and (3) that it contains an alcoholic hydroxyl group. These observations together with (4) lead to the conclusion that the substance is a hydroxy-acid. The substance was found to melt at 79°. This is an indication that the substance is glycollic acid, which melts at this temperature. Glycollic acid is converted by nitric acid into oxalic acid, which can be readily identified. The substance being studied was treated with nitric acid under the conditions used to bring about this transformation, and oxalic acid was obtained. The identification of the substance as glycollic acid was thus accomplished.

III. (1) Qualitative analysis showed that no elements other than carbon, hydrogen, or oxygen were present.

(2) The substance dissolved in cold concentrated sulphuric acid, and was precipitated on dilution.

(3) It was insoluble in cold dilute sodium hydroxide, but dissolved when heated.

(4) Tests for aldehydes, ketones, and anhydrides gave negative results.

Observation (2) indicates that the compound contains oxygen and that it may be an ester, ether, or an anhydride. The conclusion is drawn from (3) and (4) that it was an ester. The boiling-point of the compound was found to be 102°. As a number of esters boil at temperatures near 102°, the compound was identified by determining the boiling-point of the alcohol formed when it was saponified. This was found to be 97°, which is the boiling-point of propyl alcohol. As propyl acetate boils at 102°, the identification of the compound as this substance may be considered as satisfactory.

IV. (1) The substance contains chlorine.

(2) It is lighter than water and is not affected by it.

(3) It is insoluble in concentrated sulphuric acid.

(4) It does not react with acetyl chloride, bromine, sodium hydroxide, or other reagents used in the tests.

Observation (2) indicates that the compound is a monohalogen derivative of a hydrocarbon, as chlorine compounds which contain more than one halogen atom are heavier than water. Observations (3) and (4) indicate that no oxygen is present, and that the substance is saturated. The boiling-point of the substance was found to be 46°, and its specific gravity 0.89. As these are the constants for propyl chloride, the conclusion is drawn that the substance is this compound.

V. (1) The substance contains no elements other than carbon, hydrogen, and oxygen.

(2) Sodium liberates hydrogen.

(3) Acetyl chloride reacts with evolution of hydrogen chloride.

(4) Tests for aldehydes, acids, ketones, and so forth give negative results.

(5) An aqueous solution of the substance decolorizes potassium permanganate.

Observation (2) indicates the presence of a hydroxyl group, which is shown by (3) to be alcoholic. The compound is unsaturated (5), and probably contains no other group (4) than an alcoholic hydroxyl group. The boiling-point of the substance was found to be 97°. Allyl alcohol boils at this temperature. The unknown substance was treated with bromine and a bromide was obtained which boils at 214°. As allyl alcohol forms a dibromide which boils at this point, the identification of the unknown substance as this alcohol is satisfactory.

SEPARATION OF MIXTURES

331. The methods which have been outlined and illustrated above can be applied only to pure compounds. When a mixture is to be studied the problem becomes more complicated. It is often impossible to separate readily the constituents of a mixture by distillation or crystallization, and other methods based on the difference in chemical properties or solubilities of the constituents of the mixture, are often used.

A mixture which is to be examined is broken down into its constituents as far as possible by treating it with various substances, which either dissolve certain constituents of the mixture as such or convert them into soluble compounds. In effecting such solutions the following substances are frequently used: Water, which removes from the mixture substances soluble in water; a solution of hydrochloric acid, which removes basic substances insoluble in water; a solution of sodium hydroxide, which dissolves acids insoluble in water; concentrated sulphuric acid, which separates many oxygen compounds from hydrocarbons and certain halogen derivatives; and organic solvents which, in certain cases, may dissolve certain constituents of the mixture and not others.

The separation of mixtures into their constituents is illustrated by the following simple cases. The first mixture contained palmitic acid and paraffin. Neither water nor hydrochloric acid affected the mixture. When shaken with an alkali, a part dissolved which was precipitated on adding acid to the alkaline solution. The residue was unaffected by concentrated sulphuric acid. A second mixture, which contained acetone, kerosene, and amyl acetate, was first treated with water which removed acetone. Cold concentrated sulphuric acid separated the ester from the mixture of hydrocarbons. On dilution of the solution in acid, care being taken to prevent a rise in temperature, the ester was precipitated.

It is evident that if a mixture contains two or more constituents which are members of the same class of compounds or are soluble in the same reagents, separation can not be effected in the way outlined. In such cases fractional distillation or crystallization must be resorted to. A thorough knowledge of the properties of compounds is of great value in the examination of mixtures, and is of service in the purification of compounds. The purification of ethyl bromide prepared from potassium bromide, alcohol, and sulphuric acid, is an example. The bromide prepared in this way may contain ether, which is separated with difficulty from the halide by distillation. When the mixture is shaken with concentrated sulphuric acid, the ether dissolves and the bromide is unaffected. In effecting the separation of compounds it is often necessary to convert them into other substances. Thus, acetone can be separated from many other substances which are soluble in water by converting it into the difficultly soluble addition-product with sodium hydrogen sulphite.

DETERMINATION OF STRUCTURE

332. It will now be shown how the structure of a compound may be determined by a study of the composition of the compound itself and of the substances prepared from it as the result of the action of certain reagents. The following examples will illustrate the method used.

I. (1) An analysis and a determination of the molecular weight showed that the composition of the substance was that represented by the formula $C_5H_{10}O_3$.

(2) When treated with a solution of sodium hydroxide a salt of the formula $C_4H_7O_3Na$ and methyl alcohol were obtained.

(3) The acid $C_4H_8O_3$ obtained from the salt $C_4H_7O_3Na$ yielded ethyl iodide when boiled with a concentrated solution of hydriodic acid.

It is seen from the reaction which gave the results in (2),

$$C_5H_{10}O_3 + NaOH = C_4H_7O_3Na + CH_3OH$$

that the change consists in the replacement of CH_3 by Na. This together with the formation of methyl alcohol shows clearly that the compound is a methyl ester. The formation of ethyl iodide (3) shows that the acid $C_4H_8O_3$ contains a C_2H_5O group and is an ether. These facts lead to the conclusion that the structure of the acid is that represented by the formula $C_2H_5O.CH_2.COOH$ and considered with observation (2) to the view that the substance investigated has the formula $C_2H_5O.CH_2.COOCH_3$.

II. (1) Analysis and a molecular weight determination of a substance led to the formula $C_3H_4OCl_2$.

(2) When treated with cold water an acid of the composition $C_3H_5O_2Cl$ was formed.

(3) This acid was converted by shaking with silver hydroxide into the silver salt of an acid of the formula $C_3H_6O_3$.

(4) The compound $C_3H_6O_3$ yielded on oxidation an acid, $C_3H_4O_3$.

Observation (2) shows that when the compound was treated with water one chlorine atom was replaced by one hydrogen and one oxygen atom; the substance is, therefore, the chloride of an acid. Silver hydroxide (3) brought about a similar replacement of chlorine by hydroxyl; in this case the hydroxyl group introduced is that of an alcohol. The conclusion to be drawn from these two observations is that the compound $C_3H_6O_3$ is a hydroxy-monobasic acid $C_2H_4OH.COOH$. Two structures can be assigned to the substance which are in accord with this view, namely, $CH_2OH.CH_2.COOH$ and $CH_3.CHOH.COOH$. Observation (4) serves to determine which of these two is correct. In the oxidation of the substance $C_3H_6O_3$ two hydrogen atoms are replaced by one oxygen atom; the substance contains, therefore, a secondary alcohol group, and its formula is, consequently, that of α-hydroxy-propionic acid. The structural formulas for the substances involved in the changes described are $CH_3.CHCl.COCl$, $CH_3.CHCl.COOH$, $CH_3.CHOH.COOH$, and $CH_3CO.COOH$

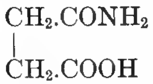
III. (1) An analysis and a molecular weight determination led to the formula $C_4H_7O_3N$.

(2) A cold solution of potassium hydroxide reacted to form the salt $C_4H_6O_3NK$.

(3) When boiled with potassium hydroxide, ammonia was set free and the salt $C_4H_4O_4K_2$ was formed.

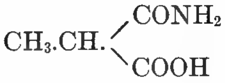
(4) The acid prepared from the salt $C_4H_4O_4K_2$ lost carbon dioxide when heated.

Observation (2) shows that the compound is a monobasic acid, as one hydrogen atom was replaced by one of potassium when the compound was treated with a cold solution of potassium hydroxide. The hot solution of the alkali brought about the replacement of NH_2 by OK; the substance is, therefore, an amide. These observations lead to the conclusion that the original substance contains a COOH group and a $CONH_2$ group. The formula is, accordingly, $C_2H_4.CONH_2.COOH$. Two compounds of this formula are possible, namely,



$$\begin{array}{l} CH_2.CONH_2 \\ | \\ CH_2.COOH \end{array}$$

and



The fourth observation shows that the second formula should be assigned to the compound, as dibasic acids which contain two carboxyl groups linked to the same carbon atom lose carbon dioxide on heating.

The examples which have been given to illustrate the methods employed to identify unknown substances, and to determine structure, have been selected on account of their simplicity and the readiness with which the observations recorded lead to definite conclusions. The steps involved in the study of many other compounds are equally obvious, but in the case of substances of more complicated structure the solution of the problem of their constitution is, at times, arrived at only after extended study. This is markedly true in the case of substances which do not contain the simple groups described up to this point. A number of important compounds which occur in nature contain their atoms linked in so-called rings and in other configurations. New principles must be developed before a conception of the structure of substances of this nature, such as uric acid, caffeine, and so forth, can be arrived at. A few examples will be given later.

When the structural formula of a compound has been deduced by the analytical method which has been illustrated, an attempt should be made to synthesise the compound. If the synthesis is carried out by reactions which can be followed step by step, and leads finally to the original compound, the structural formula assigned to it may be considered to rest on a firm experimental basis.

PROBLEMS

1. Write out in the form of a table the behavior of unsaturated compounds, hydrocarbons, acids, alcohols, aldehydes, ketones, ethers, esters, anhydrides, amines, amides, and halogen compounds with the following reagents: water, cold solution of sodium hydroxide, hot solution of sodium hydroxide, dilute hydrochloric acid, cold concentrated sulphuric acid, acetyl chloride, sodium, bromine, solution of sodium carbonate, and phenylhydrazine.

2. The behavior of a number of organic compounds with the reagents listed in the question above was studied. The positive results as well as other tests suggested by these are given below. State to what class each compound belongs, and by reference to tables of the physical properties of organic compounds determine the particular compounds described:

(*a*) The compound contains no elements other than C, H, and O, is insoluble in water and in a cold solution of sodium hydroxide, but is soluble in a hot solution of sodium hydroxide. When this solution is acidified a substance with a marked odor is formed. When the alkaline solution is distilled, the distillate gives iodoform with sodium carbonate and iodine. The boiling-point of the original substance was 121°.

(*b*) The compound contains bromine, and is insoluble in hot sodium hydroxide and in concentrated sulphuric acid. It absorbs bromine without the evolution of hydrogen bromide. The compound boiled at 71° and the compound formed by the action of bromine on it at 220°.

(*c*) The compound contains no elements other than C, H, and O. It is soluble in water, and reacts with sodium and acetyl chloride. It boils at 107° and the compound prepared from it with acetyl chloride at 117°

(*d*) The compound contains no elements other than C, H, and O. It is an oil, heavier than water, which slowly dissolves in water to form an acid solution. It dissolves in hot sodium hydroxide, and when the alkaline solution is distilled no volatile compound passes over with the steam. The compound boils at 138° and yields a compound with alcohol which boils at 76°.

(*e*) The compound contains N, is soluble in water, and is not affected by sodium hydroxide. It reacts with dilute hydrochloric acid, boils at 49°, and gives with nitrous acid a compound free from nitrogen which boils at 96°

3. Write the graphic formulas of the compounds which yielded the results given below:

(*a*) A compound of the composition $C_5H_{10}O_2$ gave the compound $C_3H_5O_2Na$ when heated with a solution of sodium hydroxide.

(*b*) The compound C_2H_2OBrCl was converted by cold water into one of the composition $C_2H_3O_2Br$. When it was heated with water at a high temperature the compound $C_2H_4O_3$ was obtained. This substance gave with potassium hydroxide the compound $C_2H_3O_3K$.

(*c*) A substance of the composition $C_3H_6O_3$ was converted into one of the composition $C_3H_4OCl_2$ by phosphorus pentachloride, and into the compound of the formula $C_3H_4O_4$ when oxidized by chromic acid.

(*d*) The formula of the compound was found to be $C_2H_5O_2N$. With a cold solution of potassium hydroxide the compound $C_2H_4O_2NK$ was formed. Nitrous acid converted the original substance into one of the composition $C_2H_4O_3$.

(*e*) The composition of the compound was $C_4H_{11}N$. It gave the compound $C_4H_{12}NCl$ with hydrochloric acid and $C_4H_{10}N_2O$ with nitrous acid.

(*f*) The compound C_2H_5NO was converted by heating with sodium hydroxide into a salt of the formula $C_2H_3O_2Na$

CHAPTER XVIII

URIC ACID AND RELATED COMPOUNDS

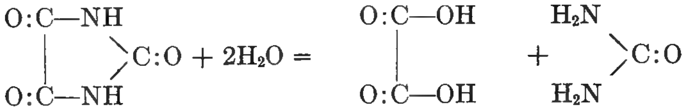
333. Uric acid was first isolated from urine in 1776 by Scheele. The acid and the compounds related to it have been investigated for many years by some of the great masters of organic chemistry. A complete account of these investigations forms one of the most interesting chapters of the science. The relationship which exists between the members of this group of compounds was finally established by the researches of Emil Fischer. Only the more important conclusions will be given here.

Uric Acid, $C_5H_4O_3N_4$, occurs in small quantity in normal urine; a man excretes daily about 0.7 grams of the acid. In gout, uric acid is deposited in the joints and under the skin as a difficultly soluble acid salt. It also occurs in the form of urinary calculi in the bladder. The ammonium salt of uric acid is the chief constituent of the excrement of birds and reptiles. The acid is most conveniently prepared from guano or the excrement of snakes.

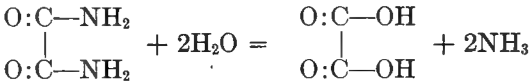
Uric acid is difficultly soluble in water; at 18.5° one part of acid dissolves in 10,000 parts of water. It is a weak dibasic acid, which forms two series of salts. The normal sodium salt has the composition $C_5H_2O_3N_4Na_2.H_2O$, and is soluble in 62 parts of water at room temperature. The acid salt, $2(C_5H_3O_3N_4Na).H_2O$, is soluble in about 1100 parts of water at 15°. Normal lithium urate is moderately soluble in water; the use of lithia-water as a remedy for gout is based upon this fact.

Conclusions as to the structure of uric acid have been arrived at from the study of the products formed as the result of the oxidation of the acid. Among the oxidation-products are parabanic acid and alloxan, which are formed when uric acid is treated with nitric acid, and allantoine, which results from the oxidation of the acid with potassium permanganate. The structure of these substances must be studied before an understanding of the configuration of uric acid can be reached.

334. Parabanic Acid, $C_3H_2N_2O_3$. — Under certain conditions an acid of this formula is obtained by oxidizing uric acid with nitric acid. The structure of parabanic acid is deduced from the decomposition which results when the acid is hydrolyzed by an alkali; urea and oxalic acid are formed: —



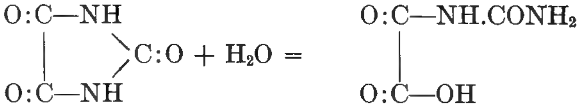
In this reaction parabanic acid resembles an amide; oxamide yields oxalic acid and ammonia on hydrolysis: —



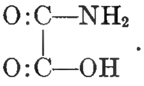
$$\begin{array}{l} O{:}C{-}NH_2 \\ \quad | \\ O{:}C{-}NH_2 \end{array} + 2H_2O = \begin{array}{l} O{:}C{-}OH \\ \quad | \\ O{:}C{-}OH \end{array} + 2NH_3$$

In parabanic acid, however, the two hydroxyl groups of oxalic acid are replaced by the residue of urea. Other dibasic acids form analogous compounds, which are called ureids. Parabanic acid is, thus, oxalyl ureid; it is also called oxalyl urea.

By careful hydrolysis, but one molecule of water is added to parabanic acid: —

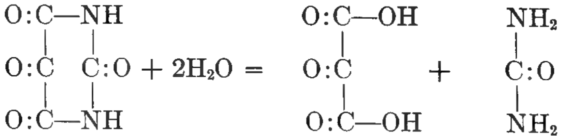


The acid formed is called oxaluric acid. It resembles oxamic acid in structure, —



$$\begin{array}{l} O{:}C{-}NH_2 \\ \quad | \\ O{:}C{-}OH \end{array}.$$

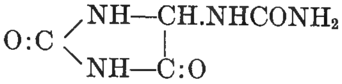
335. Alloxan, $C_4H_2N_2O_4$, is shown by its hydrolysis to be the ureid of mesoxalic acid: —



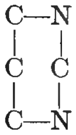
Alloxan Mesoxalic acid Urea

Alloxan crystallizes with three molecules of water, one of which is not removed when the acid is heated to 100°. (Compare glyoxylic acid, **260**.)

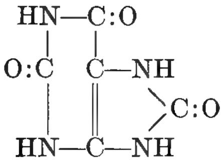
336. Allantoine, $C_4H_6O_3N_4$, is formed when uric acid is oxidized by potassium permanganate. The products of hydrolysis of allantoine, and its synthesis from glyoxylic acid and urea, lead to the structure which is represented by the formula, —



337. Structure of Uric Acid. — The formation of allantoine from uric acid is evidence that the latter contains two urea residues, and the formation of alloxan that it contains the arrangement of atoms represented by the symbols, —



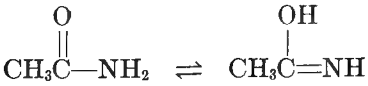
These facts lead to the view that the structure of uric acid is that represented by the formula, —



Uric acid

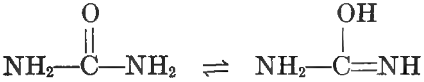
Many other facts, which can not be discussed here, lead to the same conclusion. With this structural formula as a guide, uric acid has been synthesized in a number of ways.

It is probable that a number of substitution-products of uric acid are derived from a tautomeric form of the acid. It will be recalled that there is evidence for the view that certain compounds related to amides are derived from a tautomeric form of these compounds (**179**): —



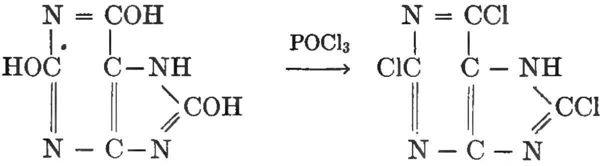
$$\mathrm{CH_3}\overset{\overset{\mathrm{O}}{\|}}{\mathrm{C}}\mathrm{{-}NH_2} \rightleftharpoons \mathrm{CH_3}\overset{\overset{\mathrm{OH}}{|}}{\mathrm{C}}\mathrm{{=}NH}$$

In some of its reactions urea behaves as if it had a structure similar to the tautomeric form of amides: —



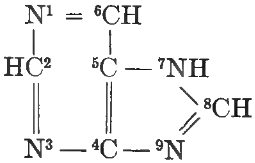
$$NH_2-\overset{\overset{O}{\|}}{C}-NH_2 \rightleftharpoons NH_2-\overset{\overset{OH}{|}}{C}=NH$$

With certain reagents, for example phosphorus oxychloride, uric acid acts in a manner which indicates that it has the tautomeric configuration: —



The product formed by this reaction is called trichlorpurine.

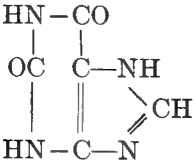
338. Purine is obtained from trichlorpurine by treatment with hydriodic acid, which converts it into diiodopurine, and subsequent reduction of the latter by zinc-dust. Purine is of interest as it is the compound from which uric acid and xanthine may be considered as derived by substitution. For convenience of reference the atoms in purine are numbered in the following way: —



Purine

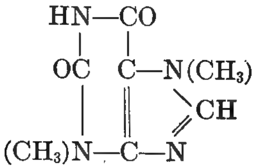
The compound formed by the action of phosphorus oxychloride on uric acid is, accordingly, 2,6,8-trichlorpurine.

339. Xanthine, 2,6-dioxypurine,



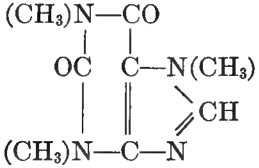
is present in the tissues of the body, and is an important constituent of certain proteins which occur in the body-cells. The salts formed by xanthine with bases are decomposed by carbonic acid; those formed with acids are more stable, although the compound is only weakly basic.

340. Theobromine, 3,7-dimethyl-2,6-dioxypurine,



is a dimethyl-substitution-product of xanthine. It is prepared from cocoa beans, and is present in chocolate to the extent of from 1 to 2 per cent. Theobromine is a white crystalline powder which is soluble with difficulty in water. It sublimes unchanged at about 290°. It forms with strong acids salts, which crystallize well and are hydrolyzed by water. It also acts as a weak acid. It can be prepared from xanthine by treating the lead salt of the latter with methyl iodide.

341. Caffeine or **theine,** 1, 3, 7-trimethyl-2, 6-dioxypurine,



is a constituent of coffee and tea. Coffee beans contain about one per cent of caffeine. The compound crystallizes from water in needles, which contain one molecule of water of crystallization. Anhydrous caffeine melts at 234.5°. It dissolves in about 70 parts of water at 16° and in about 2 parts at 65°. Caffeine forms well characterized salts with acids; the nitrate has the composition $C_8H_{10}N_4O_2.HNO_3$. Caffeine has been prepared from theobromine by introducing into the latter a third methyl group. The structures of caffeine and theobromine have been determined by a study of the products formed on their oxidation. Caffeine yields, when carefully oxidized, dimethylalloxan and methylurea.

CHAPTER XIX

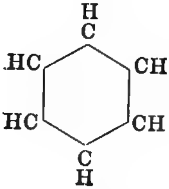
CYCLIC HYDROCARBONS

342. When organic compounds were first carefully studied they were divided into two classes which were designated by the terms *aliphatic* and *aromatic*. To the first class belong the compounds which have been discussed up to this point. The term aliphatic is derived from the Greek word signifying fat. Many of the acids which can be derived from the hydrocarbons of the methane series were first isolated from fats. The relation seemed an important one, and, consequently, the acids so derived and the compounds prepared from them were called aliphatic compounds. The term aromatic was applied to certain substances found in the vegetable kingdom which possess an agreeable odor, such as oil of bitter almonds, vanilla, and oil of wintergreen. This apparently arbitrary classification of organic substances has survived, as investigation has shown that the chemical properties of the two classes of compounds are markedly different. The possession of an odor is not characteristic, however, of the so-called aromatic compounds. The study of the chemical composition of these compounds has shown that they are all derived from the hydrocarbon benzene, C_6H_6. The chemical properties which differentiate the aromatic compounds, more or less distinctly, from the aliphatic compounds, result from the fact that in many of its reactions with other substances benzene differs markedly from the aliphatic hydrocarbons.

More than one-half of the organic compounds studied up to the present time belong to the aromatic series.. Many of these are manufactured in large quantities, and are used as drugs, dyes, flavoring extracts, food preservatives, and so forth.

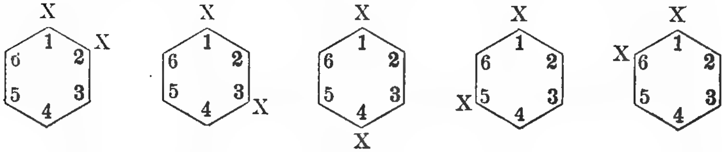
343. Structure of Benzene. — It is necessary at the outset to form a conception of the structure of the benzene molecule. Benzene contains but six hydrogen atoms in combination with six carbon atoms. This fact would lead to the view that the hydrocarbon is a highly unsaturated compound, as hexane, the paraffin which contains six carbon atoms, has the composition C_6H_{14}. In most of its reactions benzene acts like a saturated compound. Under certain conditions, however, it unites with bromine and forms the compound $C_6H_6Br_6$. If benzene were an unsaturated compound related to hexane, it should unite with eight atoms, as six carbon atoms joined as such atoms are joined in the aliphatic compounds, can hold in combination fourteen univalent atoms. This fact shows clearly that we must look for an arrangement of atoms in benzene quite different from that found among the unsaturated compounds of the aliphatic series.

A definite view of the structure of benzene is arrived at from a consideration of two important facts. These are, first, benzene forms but one monosubstitution-product with bromine or other atom or group, and, second, when two hydrogen atoms are replaced by two atoms or groups, but three isomeric disubstitution-products can exist. The fact that but one brombenzene, C_6H_5Br, exists, indicates that all six hydrogen atoms of benzene bear the same relation to the molecule. An elaborate series of experiments showed that all the hydrogen atoms are alike. One after another was replaced by the amino group, and the products obtained in all cases were identical. A number of structural formulas of benzene have been devised to fulfil the requirement of the equivalence of the six hydrogen atoms. Kekulé suggested that benzene consisted of six CH groups joined in a ring: —



Such a configuration is symmetrical, and is in accord with the fact that but one monosubstitution-product of benzene is possible.

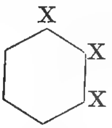
This view of the structure of benzene must now be tested in regard to the fact that three, and only three, disubstitution-products exist. The formulas of the disubstitution-products of a hydrocarbon of the structure indicated are given below. For brevity it is usual to represent the structure of benzene by a hexagon, it being assumed that a CH group is situated at each angle. A symbol placed at an angle indicated that the hydrogen atom has in this place been replaced by the atom indicated by the symbol. The angles are frequently numbered for reference.



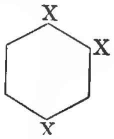
As the formula assigned to benzene is symmetrical, it is evident that the formula in which the X's are in the positions 1, 2 and 1, 6 are identical. Those in which the substituents are in the positions 1, 3 and 1, 5 are likewise the same. It is, thus, seen that a hydrocarbon which consists of six CH groups arranged in a ring should yield three disubstitution-products. This conclusion is further evidence of the correctness of the ring structure assigned to benzene.

In order to designate the structure of disubstitution-products, names have been assigned to the isomers. Those in which the substituents are joined to adjacent carbon atoms (1, 2) are called *ortho* compounds, those in which the substituents are in the positions 1, 3 are called *meta* compounds, and those in the positions 1, 4 are *para* compounds.

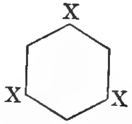
The correctness of the formula for benzene can be tested further by considering the relation between the theory and the facts in the case of tri- and tetra-substitution-products. The theory leads to the view that trisubstitution-products which contain but one kind of substituent, should exist in three forms. Three, and only three, such isomers exist. The formulas and names of these are as follows: —



Adjacent or
neighboring
1, 2, 3



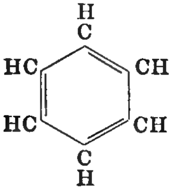
Unsymmetrical
1, 2, 4



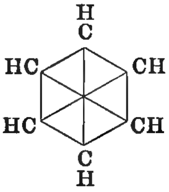
Symmetrical
1, 3, 5

If the substituents are dissimilar, a larger number of isomers is possible. The substitution-products which contain four similar groups exist in three forms — the number which is in accord with the theory. On account of the ring structure assigned to benzene and its homologues, they are called *cyclic* compounds.

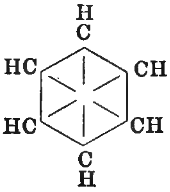
The formula of benzene which has been discussed does not take into account the fourth valence of the carbon atoms. Many suggestions have been put forward in regard to the position of this fourth bond. The formulas of Kekulé, Claus, and Armstrong and Baeyer are as follows: —



Kekulé



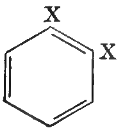
Claus

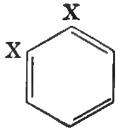


Armstrong
and
Baeyer

In the formula of Kekulé the carbon atoms are joined alternately by double bonds. According to Claus, each carbon atom is in combination with a carbon atom opposite to it in the molecule. The so-called centric formula of Armstrong and Baeyer is meant to indicate that the combining powers of the carbon atoms which are not utilized in the ring formation and in holding the hydrogen atoms, mutually neutralize one another, and no carbon atom is united directly to another carbon atom by the fourth bond.

There are objections which can be raised to all these formulas. While that of Kekulé accounts for the fact that benzene can unite with six bromine atoms, as it contains three double bonds, it is not in accord with the fact that but one ortho dibrombenzene exists. According to this formula, ortho compounds should exist in the forms represented by the formulas, —





In the compound represented by the first formula the substituents are in combination with carbon atoms linked by a double bond and, in the second, by a single bond. Kekulé overcame this objection by the assumption that the combination of the fourth bonds was dynamic, that is, that the double union shifted from between the carbon atoms numbered 1 and 2 to those numbered 1 and 6. A similar shifting took place also with the other double bonds. Objections have been raised to the other formulas. These are particularly forceful when the arrangement of the atoms in space is considered. The question in regard to the fourth valence of the carbon atoms in benzene is still an open one.

In most of its reactions benzene acts like a saturated compound, and the fourth valence of the carbon atoms does not come into play. The hydrocarbon does not react with an aqueous solution of potassium permanganate, and does not show, therefore, the behavior which is characteristic of the unsaturated hydrocarbons of the aliphatic series.

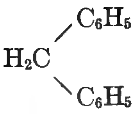
344. Sources of Aromatic Compounds. — Many compounds which may be considered as derived from benzene, occur in the vegetable kingdom. Some of these will be described later. The source which yields the large quantities of benzene and its homologues used in the manufacture of many substances of industrial importance, is coal-tar.

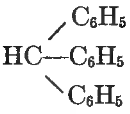
Coal-tar is formed in the manufacture of illuminating gas from bituminous coal. As obtained from the condensers, through which the gas is passed to free it from liquids, it is a black oily liquid which has a disagreeable odor. The crude tar is used to some extent for preserving wood, making tar-paper, and as a protective paint. It is separated into its constituents by distillation and by chemical means. Coal-tar contains three classes of compounds: hydrocarbons, which are not affected by acids or alkalies; phenols, which dissolve in alkalies; and basic substances which dissolve in acids. The tar is first distilled, and the distillate collected in fractions. The " first runnings " or " first light oil," which is collected up to 105°, contains water, ammonium salts, the more volatile oils, and a small quantity of the heavier oils. The " light oil " is collected between 105° and 210°: it contains benzene, toluene, xylenes, and small quantities of thiophene, phenols, and pyridine bases. The next fraction, called " carbolic oil," which is collected up to 240°, contains phenols and naphthalene. The " creasote oils," which are collected between 240° and 270°, contain naphthalene, cresols, naphthol, and other compounds. The product obtained from this fraction after the removal of naphthalene, is used in preserving timber and railroad sleepers, and in destroying vermin. The "anthracene oil," which distills above 270°, contains about 10 per cent of anthracene together with carbazol, liquid oils, and solid hydrocarbons, such as phenanthrene and chrysen. The *pitch* left in the still is used as a black varnish for painting metal work, and for making tarred paper. It is mixed with asphalt for making pavements.

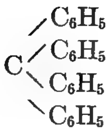
The products obtained by the first distillation are redistilled after treatment with acid and alkali to separate the neutral, basic, and acidic substances which they contain. From the higher boiling distillates naphthalene and anthracene crystallize out on cooling. These hydrocarbons are separated by filtration and pressure, and are purified by distillation or sublimation. Benzene is obtained from the "light oil" by distillation. The fraction collected up to 100° is called "90 per cent benzol," as that per cent of the mixture distills over below 100°. It contains about 70 per cent benzene, 24 per cent toluene, and some xylenes. The fraction which distills between 140° and 170° is called "solvent naphtha" or "benzine." It consists mainly of xylenes, cumenes, and other higher homologues of benzene, and is used as a solvent for resins and rubber, to enrich illuminating gas, and as a cleansing agent for fabrics. Phenol, or carbolic acid, is separated from the "carbolic oil" by treatment with sodium hydroxide, in which the phenol is soluble. The alkaline solution, after separation from insoluble oils, is acidified, when the phenol separates as an oil.

345. Classes of Aromatic Hydrocarbons. — A large number of hydrocarbons may be considered as derivatives of benzene formed by the replacement of one or more hydrogen atoms by radicals. Benzene bears the same relation to the aromatic hydrocarbons that methane bears to the paraffins. Toluene, which has the formula $C_6H_5.CH_3$, is methyl-benzene; the three xylenes are dimethyl-benzenes, $C_6H_4.(CH_3)_2$; cymene is para-methyl-isopropyl-benzene, $C_6H_4.(CH_3)(C_3H_7)$, and so forth. The radicals which are joined to the benzene ring are called "side-chains." The side-chain may be a radical derived from an unsaturated hydrocarbon. Among the hydrocarbons of this class are styrene, $C_6H_5.CH=CH_2$, which is a phenyl derivative of ethylene, and phenyl-acetylene, $C_6H_5.C\equiv CH$.

An important class of hydrocarbons includes substances which contain two or more benzene rings. Such hydrocarbons may be considered as derived from methane and its homologues by replacing hydrogen atoms by phenyl radicals. Diphenylmethane, triphenylmethane, and tetraphenylmethane, the formulas of which are given below, belong to this class.

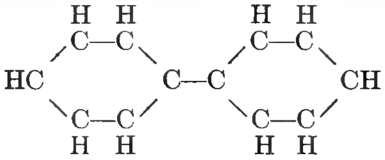




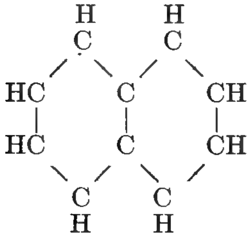


Analogous derivatives of ethane and other hydrocarbons are known. Diphenylethane, $C_6H_5CH_2.CH_2C_6H_5$, and tetraphenylethane, $(C_6H_5)_2CH.CH(C_6H_5)_2$, are examples. Similar substitution-products of unsaturated hydrocarbons are of interest. Tetraphenylethylene, $(C_6H_5)_2C=C(C_6H_5)_2$, will be described later.

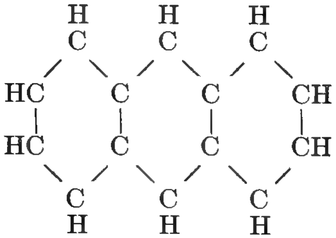
Important hydrocarbons are known in which two or more benzene rings are more directly united than in the cases just mentioned. Diphenyl, $C_6H_5.C_6H_5$, consists of two rings in direct combination. Derivatives of this hydrocarbon exist in which one or more hydrogen atoms are replaced by alkyl radicals. In these compounds the two benzene rings are joined by a single bond. The structure of diphenyl is represented by the formula,



Naphthalene and anthracene, which contain benzene rings, are built up in a different way. The formulas for these hydrocarbons are, —



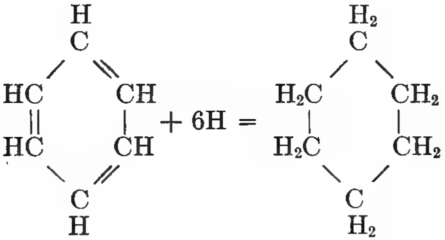
Naphthalene



Anthracene

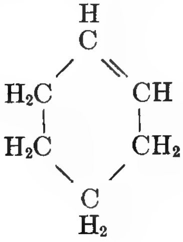
The hydrocarbons of this class resemble closely the simpler benzene derivatives.

346. The so-called **hydroaromatic compounds** are derived from hydrocarbons which are related in structure to benzene, but differ markedly from the latter in chemical properties. It has been stated that benzene can unite with six bromine atoms and form a compound in which the six latent bonds of the carbon atoms are brought into play. Under certain conditions benzene adds six hydrogen atoms; a hydrocarbon is formed, which resembles closely the paraffins in chemical properties. As its formula is C_6H_{12}, and as it is a saturated compound, the configuration of the molecule must be unlike that of hexane which has the formula C_6H_{14}. The simplest explanation of the reaction which takes place when hydrogen is added to benzene, is that each carbon atom unites with one hydrogen atom and the ring remains intact. The reactions of the hydrocarbon, which is called hexamethylene, cyclohexane, or hexahydrobenzene, are in accord with this view of its structure. Adopting the Kekulé formula of benzene, the reaction between benzene and hydrogen may be expressed by the following equation: —



Hexamethylene is so-called because it consists of six methylene (CH_2) radicals in combination. It resembles the saturated hydrocarbons in properties. Similar derivatives have been obtained from the homologues of benzene.

By regulating the addition of hydrogen to benzene and its homologues, either two or four hydrogen atoms can be added. Tetrahydrobenzene, or cyclohexene, C_6H_{10},



is a hydrocarbon from which important substances occurring in nature are derived. Dihydrobenzene and tetrahydrobenzene exhibit the properties which are characteristic of the unsaturated hydrocarbons related to ethylene.

347. Preparation of Aromatic Hydrocarbons. — A number of methods of preparing the hydrocarbons of this class are general in their application. The more important will be mentioned here. Certain special methods will be described under the compounds to which they may be applied with advantage.

The *Fittig synthesis* is an application of the Wurtz synthesis (**21**) to the preparation of aromatic compounds. It is carried out by treating an ethereal solution of a halogen derivative of an aromatic hydrocarbon and an alkyl halide with sodium. Toluene may be prepared in this way from brombenzene and methyl iodide: —

$$C_6H_5Br + CH_3I + 2Na = C_6H_5.CH_3 + NaI + NaBr$$

When dibrombenzene is used the halogen atoms are replaced by two alkyl groups. The method is of particular value, as by means of it compounds of definite structure may be prepared. Metadibrombenzene is converted, for example, into metaxylene when treated with methyl iodide and sodium.

Two or more benzene rings can be united by the application of the Fittig synthesis. Brombenzene and sodium yield diphenyl: —

$$2C_6H_5Br + 2Na = C_6H_5.C_6H_5 + 2NaBr$$

Other methods of preparation analogous to the Fittig synthesis are frequently used. In the case of certain compounds the halogen atoms are more readily removed by zinc or silver. Tetraphenylethane is conveniently prepared by treating a solution of diphenylbrommethane with zinc: —

$$2(C_6H_5)_2CHBr + Zn = (C_6H_5)_2CH.CH(C_6H_5)_2 + ZnBr_2$$

When diphenyldichlormethane is treated with zinc a derivative of ethylene is formed: —

$$2(C_6H_5)_2CCl_2 + 2Zn = (C_6H_5)_2C:C(C_6H_5)_2 + 2ZnCl_2$$

Friedel and Crafts Synthesis. — In the presence of anhydrous aluminium chloride, aliphatic halogen compounds react with aromatic hydrocarbons and form condensation-products as the result of the elimination of halogen hydride. Thus, when a mixture of benzene and aluminium chloride is treated with methyl chloride, toluene is formed: —

$$C_6H_6 + CH_3Cl \overset{AlCl_3}{=} C_6H_5.CH_3 + HCl$$

As toluene reacts under the same conditions with methyl chloride to form xylene (dimethylbenzene), and the latter to form trimethylbenzene, and so forth, it is evident that a pure compound cannot be obtained readily by this reaction. The hydrocarbons formed may be separated by fractional distillation.

The Friedel and Crafts synthesis is of particular value in the preparation of certain classes of hydrocarbons. Diphenylmethane is best prepared in this way from benzylchloride, $C_6H_5CH_2Cl$: —

$$C_6H_5CH_2Cl + C_6H_6 \overset{AlCl_3}{=} C_6H_5CH_2C_6H_5 + HCl$$

Chloroform and benzene furnish a good yield of triphenylmethane: —

$$CHCl_3 + 3C_6H_6 \overset{AlCl_3}{=} CH(C_6H_5)_3 + 3HCl$$

It is important to note that halogen compounds in which the halogen atom is joined to a carbon atom in the benzene ring, can not be used instead of the halogen derivatives of the paraffin hydrocarbons. Chlorbenzene and benzene do not interact under the influence of aluminium chloride. The presence of the halogen atom in the benzene ring does not interfere, however, with the condensation. Chloroform and chlorbenzene yield trichlortriphenylmethane. In brief, the halogen atom which is eliminated as halogen hydride, must be one which is not linked to a carbon atom in a ring, and the hydrogen atom so eliminated must be one which is linked to such a carbon atom.

348. Acyl chlorides react with aromatic hydrocarbons in the presence of aluminium chloride. The reaction furnishes a convenient method of preparing ketones. The preparation of methylphenyl ketone is an example: —

$$CH_3COCl + C_6H_6 \overset{AlCl_3}{=} CH_3COC_6H_5 + HCl$$

The manner in which aluminium chloride effects the condensation of a halide and a hydrocarbon has been carefully studied. It has been found that in certain cases the aluminium chloride forms an addition-product with the hydrocarbon, which enters into reaction with the alkyl or other halide. In other cases, the inorganic halide forms a compound with the organic halide, which, in turn, reacts with the hydrocarbon. Intermediate products have been isolated in a number of cases. The one formed from aluminium chloride and the chloride of benzoic acid, C_6H_5COOH, can be obtained in well-formed crystals; it has the composition $C_6H_5COCl.AlCl_3$. When this compound is treated with benzene, reaction takes place and a halogen atom is replaced by the phenyl radical: —

$$C_6H_5COCl.AlCl_3 + C_6H_6 = C_6H_5COC_6H_5.AlCl_3 + HCl$$

The compound of aluminium chloride and the resulting ketone, in this case diphenyl ketone, can be obtained in crystalline condition. When treated with water it is decomposed and the ketone and aluminium chloride are formed.

The results obtained in the study of the mechanism of these reactions are of the greatest importance, as they throw light on the nature of so-called catalytic reactions. For a long time the part played by aluminium chloride in effecting condensations was unknown. The substance was said to be a catalytic agent. The results just outlined show that, in this case at least, the reaction is brought about as the result of the formation of an addition-product of one of the reacting substances and the catalytic agent, and that the product so formed possesses properties unlike those of the compounds from which it is formed. Benzoyl chloride will not react with benzene; the addition-product of benzoyl chloride and aluminium chloride will react. We have already learned that the reactivity of a halogen atom is determined by the nature of the group with which it is in combination. Ethyl chloride is very stable toward water; acetyl chloride reacts with it very rapidly. The difference between the two compounds in this respect is due to the fact that one contains oxygen and the other does not. It is reasonable that the addition of aluminium chloride to a compound should materially alter the reactivity of the elements which the compound contains. Recent work in other directions in the study of catalytic action indicates strongly that, in many cases, the effect of the catalytic agent is brought about as the result of its union with one of the reacting substances.

349. Grignard's Synthesis. — Magnesium reacts with halogen derivatives of the aromatic hydrocarbons as well as with those derived from the paraffins. The compounds so formed are decomposed by water, and hydrocarbons are formed. By the application of this method a halogen compound can be converted into the corresponding hydrocarbon: —

$$C_6H_5MgBr + H_2O = C_6H_6 + Mg.OH.Br$$

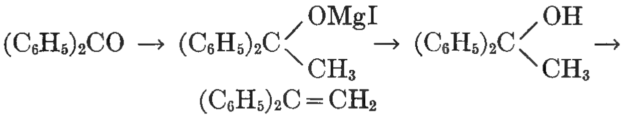
The magnesium compounds react, also, with halides: —

$$C_6H_5CH_2Cl + CH_3MgI = C_6H_5CH_2CH_3 + MgI.Cl$$

Tetraphenylmethane may be prepared by the reaction expressed by the following equation: —

$$(C_6H_5)_3C.Cl + C_6H_5MgBr = (C_6H_5)_4C + MgBrCl$$

Unsaturated hydrocarbons are readily prepared from ketones and acid chlorides by Grignard's synthesis. The reaction first yields a derivative of a tertiary alcohol, which at a higher temperature loses water and passes into a hydrocarbon. Diphenyl ketone, for example, gives with magnesium methyl iodide diphenylethylene: —



$$(C_6H_5)_2CO \rightarrow (C_6H_5)_2C\begin{matrix} / OMgI \\ \backslash CH_3 \end{matrix} \rightarrow (C_6H_5)_2C\begin{matrix} / OH \\ \backslash CH_3 \end{matrix} \rightarrow (C_6H_5)_2C{=}CH_2$$

350. Other Syntheses. — As in the case of the aliphatic compounds, aromatic hydrocarbons are formed when salts of acids are distilled with sodium hydroxide or soda-lime. Benzene can be prepared from benzoic acid in this way: —

$$C_6H_5.COONa + NaOH = C_6H_6 + Na_2CO_3$$

The sulphonic acids derived from the aromatic hydrocarbons are decomposed when heated with water under pressure. Hydrochloric acid facilitates the reaction. Toluene sulphonic acid yields toluene: —

$$CH_3.C_6H_4.SO_3H + HOH = CH_3.C_6H_5 + H_2SO_4$$

The hydroxyl derivatives of the aromatic hydrocarbons are reduced when heated with zinc-dust: —

$$C_6H_5OH + Zn = C_6H_6 + ZnO$$

351. The **hydroaromatic compounds** are prepared by reducing benzene derivatives. The method of Sebatier and Senderens is particularly valuable for this purpose. Hexamethylene is formed when hydrogen and the vapor of benzene are passed over finely-divided nickel: —

$$C_6H_6 + 3H_2 = C_6H_{12}$$

Dihydrobenzene and similar compounds are prepared by a method which is analogous to that used to prepare unsaturated hydrocarbons of the ethylene series, namely, the elimination of halogen hydride from halogen derivatives of hexahydrobenzene:

$$C_6H_{10}Cl_2 + 2KOH = C_6H_8 + 2KCl + H_2O$$

352. Characteristic Reactions of the Aromatic Compounds. — It has been stated that the aromatic compounds differ markedly from the paraffins and the unsaturated hydrocarbons related to ethylene and acetylene. The reactions which take place when benzene and its derivatives are treated with nitric acid, sulphuric acid, or oxidizing agents are characteristic of this group of compounds. Only the higher paraffins react with nitric acid, and in the case of these compounds reaction results to but a slight degree and only after heating for many hours (**26**). The aromatic hydrocarbons and their substitution-products form well characterized compounds when treated with nitric acid. When benzene is warmed with concentrated nitric acid nitrobenzene is formed: —

$$C_6H_6 + HO.NO_2 = C_6H_5.NO_2 + H_2O$$

The nitro-compounds are of the greatest importance and will be discussed fully later.

Benzene is converted into benzene sulphonic acid when heated with concentrated sulphuric acid: —

$$C_6H_6 + HO.SO_2.OH = C_6H_5.SO_2.OH + H_2O$$

The sulphonic acid may be considered as derived from sulphuric acid by the replacement of a hydroxyl group by a radical.

The paraffins resist to a marked degree the action of oxidizing agents. The aromatic compounds which contain side-chains are oxidized when treated with dilute nitric acid, potassium chromate, potassium permanganate, or other active oxidizing agents. Toluene and ethyl benzene are converted by oxidizing agents into benzoic acid:—

$$C_6H_5.CH_3 + 3O = C_6H_5.COOH + H_2O$$
$$C_6H_5.CH_2CH_3 + 6O = C_6H_5.COOH + CO_2 + H_2O$$

In general, a side-chain, whatever its length or configuration, is converted by active oxidizing agents into a single carboxyl group. A xylene, which contains two methyl groups joined to different carbon atoms, yields a dibasic acid on oxidation:—

$$C_6H_4(CH_3)_2 + 6O = C_6H_4(COOH)_2 + 2H_2O$$

AROMATIC HYDROCARBONS

353. Benzene, C_6H_6, was discovered in 1825 by Faraday in the liquid obtained from compressed oil gas. It was first isolated from coal-tar in 1845 by A. W. Hofmann. The hydrocarbon is of the greatest importance on account of the fact that it is the substance from which the aromatic compounds are derived. It is obtained in large quantities from coal-tar, and is used in the manufacture of many compounds which find extensive use. Benzene has recently been isolated from California petroleum. Benzene melts at 5.4° and boils at 80.4°; its specific gravity is 0.8736 ($\frac{20°}{4°}$). That obtained from coal-tar contains thiophene, C_4H_4S, from which it can not be separated by distillation. The sulphur-compound is extracted from benzene by shaking the latter with concentrated sulphuric acid. The pure hydrocarbon is obtained by the process of alternate freezing and melting, which has been described (**7**).

Benzene is formed when acetylene is passed through a hot tube:—

$$3C_2H_2 = C_6H_6$$

It is also obtained when sodium benzoate is heated with sodium hydroxide. Pure benzene, free from thiophene, was first obtained in this way. Some of the earlier investigations of benzene were carried out with the hydrocarbon prepared from benzoic acid. The reaction is analogous to that by which methane may be prepared from acetic acid: —

$$C_6H_5COONa + NaOH = C_6H_6 + Na_2CO_3$$

Benzene reacts with chlorine in the sunlight to form an addition-product called benzene hexachloride, $C_6H_6Cl_6$. The effect of a carrier[1] on the reaction between a halogen and a hydrocarbon can be readily shown when benzene is treated with bromine. When bromine is added to benzene, no reaction appears to take place at first. If a little powdered iron or aluminium is added, reaction soon begins and hydrogen bromide is rapidly evolved. If equal molecular weights of the hydrocarbon and halogen are used, and the mixture is kept cold, the chief product of the reaction is brombenzene. If more bromine is used and the mixture is allowed to grow warm, paradibrombenzene is formed.

When benzene is warmed and shaken with concentrated sulphuric acid, it dissolves slowly and is converted into benzene sulphonic acid, which is soluble in water, and resembles sulphuric acid somewhat in physical properties. In order to increase the yield of sulphonic acid a mixture of sulphuric acid and sulphur trioxide is often used. The reaction takes place according to the equation, —

$$C_6H_6 + HO.SO_2OH = C_6H_5.SO_2OH + H_2O$$

Hot concentrated nitric acid converts benzene into nitrobenzene, which is a heavy oil, insoluble in water: —

$$C_6H_6 + HO.NO_2 = C_6H_5.NO_2 + H_2O$$

When a large excess of nitric acid is used metadinitrobenzene is formed. In the introduction of nitro groups into hydrocarbons a mixture of nitric acid and sulphuric acid is generally used.

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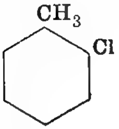
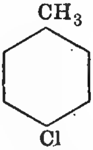
[1] The so-called halogen-carriers, such as iron, iodine, and aluminium chloride, are catalytic agents, which increase the rate of reaction between the halogens and organic compounds.

354. Toluene, $C_6H_5.CH_3$, is obtained from coal-tar. It boils at 111° and has the specific gravity 0.865 $\left(\frac{20^\circ}{4^\circ}\right)$. It may be prepared by the use of the general methods which have been described.

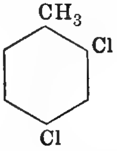
The reaction of toluene with chlorine and bromine presents some points of interest. When the hydrocarbon is treated with chlorine in the sunlight, or the halogen is passed into the boiling hydrocarbon, substitution in the side-chain takes place. In this way compounds of the formula $C_6H_5.CH_2Cl$, $C_6H_5.CHCl_2$, and $C_6H_5.CCl_3$ are formed. The compounds are called, respectively, benzyl chloride, benzal chloride, and benzotrichloride. When the halogen reacts with toluene in the presence of a carrier, the substituent enters the ring, and chlortoluenes are formed. The number of chlorine atoms which enter is determined by the amount of halogen used and the temperature. A mixture of the ortho and para compounds is first obtained; a dichlortoluene and a trichlortoluene can also be formed. The structure of these compounds is represented by the formulas: —



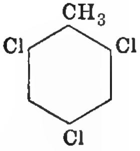
o-chlortoluene



p-chlortoluene



2, 4-dichlortoluene



2, 4, 6-trichlortoluene

Analogous bromine derivatives can also be prepared. The behavior of the homologues of benzene with chlorine and bromine, is similar to that with toluene. When the halogen reacts with the hydrocarbon in the absence of a carrier, substitution in the side-chain takes place. In the presence of a carrier the substituent enters the ring. It will be recalled that the paraffins react with chlorine in the sunlight, and substitution-products are formed. When toluene is treated with the halogen under the same conditions it acts as a derivative of methane, phenylmethane, $CH_3.C_6H_5$, and the hydrogen atoms joined to the methane carbon atom are replaced.

Nitric acid and sulphuric acid react with toluene and nitro-compounds and sulphonic acids are formed as the result of the replacement of hydrogen atoms in the ring. The positions in the molecule taken by the entering group are the same as those taken by the halogens.

When toluene is boiled with dilute nitric acid or a solution of potassium chromate and sulphuric acid, the side-chain is oxidized to a carboxyl group, and benzoic acid is formed: —

$$C_6H_5.CH_3 + 3O = C_6H_5.COOH + H_2O$$

The reaction takes place slowly on account of the insolubility of the hydrocarbon in water. The oxidation of the side-chains in compounds which are soluble in water takes place, in general, with ease. For example, toluic acid is readily oxidized to phthalic acid when warmed with a solution of potassium permanganate:

$$CH_3.C_6H_4.COOH + 3O = C_6H_4(COOH)_2 + H_2O$$

355. Xylenes, $C_6H_4(CH_3)_2$. — The three xylenes occur in coal-tar. On account of the fact that their boiling-points are so nearly alike, they can not be separated by distillation. Orthoxylene boils at 141.9°, metaxylene at 139.2°, and paraxylene at 138°. They can be prepared in the pure condition by Fittig's synthesis. They can be obtained, nearly pure, from coal-tar by chemical means, the separation being effected by a method which is based on the difference in reactivity of the isomers with sulphuric acid and with oxidizing agents.

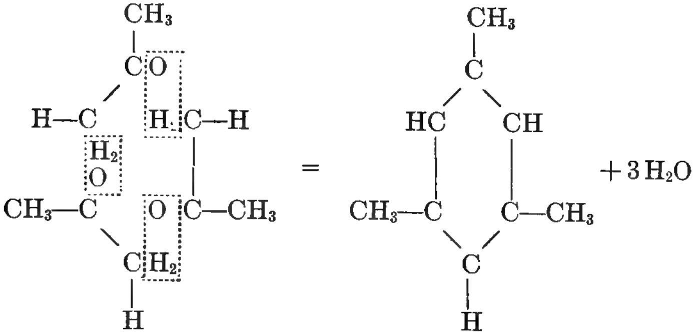
356. Cymene, $C_6H_4(CH_3)(i\text{-}C_3H_7)(1, 4)$, is para-methylisopropylbenzene. It is a constituent of a number of essential oils, such as oil of caraway, oil of lemon, oil of thyme, and oil of eucalyptus. It can be prepared by Fittig's synthesis from *p*-bromisopropylbenzene. It is most readily prepared by warming camphor with phosphorus pentoxide: —

$$C_{10}H_{16}O \overset{P_2O_5}{=} C_{10}H_{14} + H_2O$$

Cymene boils at 175° and has the specific gravity 0.856 $(\frac{20^\circ}{4^\circ})$.

357. Mesitylene, $C_6H_3(CH_3)_3(1, 3, 5)$, symmetrical trimethylbenzene, is found in coal-tar. It boils at 164.5° and has the specific gravity 0.8694$(\frac{9.8^\circ}{4^\circ})$. The hydrocarbon is most readily obtained by the action of concentrated sulphuric acid on acetone.

If the two substances are mixed and distilled after standing some time, mesitylene is obtained. The yield is small, being from ten to twenty per cent of that calculated from the weight of acetone used. The reaction consists in the removal of water from acetone: —



The condensation leads to the view that mesitylene has the symmetrical structure — a fact which has been established by evidence independent of this synthesis.

358. Diphenylmethane, $(C_6H_5)_2CH_2$, is best prepared from benzyl chloride, $C_6H_5CH_2Cl$, and benzene by the Friedel and Crafts synthesis. It melts at 26° and boils at 262°. Homologues of this compound can be prepared from aldehydes and aromatic hydrocarbons by the action of sulphuric acid. Thus, aldehyde or acetal and benzene when shaken with sulphuric acid give diphenyl-methyl-methane (unsymmetrical diphenylethane):

$$CH_3CHO + C_6H_6 = CH_3CH(C_6H_5)_2 + H_2O$$

Ditolylmethane may be prepared from methylene chloride and toluene in the presence of aluminium chloride: —

$$CH_2Cl_2 + 2C_6H_5.CH_3 = CH_2(C_6H_4.CH_3)_2$$

Diphenylmethane and similar compounds are converted into nitro derivatives when heated with nitric acid, and into sulphonic acids by sulphuric acid. When oxidized with chromic acid, diphenylmethane gives diphenylketone (benzophenone): —

$$(C_6H_5)_2CH_2 + O_2 = (C_6H_5)_2CO + H_2O$$

359. Triphenylmethane, $(C_6H_5)_3CH$, is an important hydrocarbon on account of its relation to the triphenylmethane dyes. It is prepared from chloroform and benzene by the Friedel and Crafts synthesis: —

$$CHCl_3 + 3C_6H_6 = CH(C_6H_5)_3 + 3HCl$$

The reaction is not as simple a one as indicated by this equation. A number of products are formed from which it is necessary to separate triphenylmethane by distillation and crystallization. The hydrocarbon melts at 93° and boils at 359°. It forms a well characterized addition-product with benzene of the formula $(C_6H_5)_3CH.C_6H_6$, which crystallizes in rhombohedra, melts at 76°, and effloresces in the air. When dissolved in cold fuming nitric acid, triphenylmethane is converted into a trinitro derivative, in which the nitro groups are in the para position to the methane carbon atom. With chlorine, triphenylchlormethane, $(C_6H_5)_3CCl$, and with oxidizing agents, triphenylcarbinol, $(C_6H_5)_3C.OH$, are formed.

360. ***s*****-Diphenylethane**, $C_6H_5CH_2.CH_2C_6H_5$, is also called dibenzyl. It is formed from benzylchloride by the Wurtz synthesis: —

$$2C_6H_5CH_2Cl + 2Na = C_6H_5CH_2.CH_2C_6H_5 + 2NaCl$$

The method of preparing unsymmetrical diphenylethane $(C_6H_5)_2CH.CH_3$, was mentioned under diphenylmethane. The symmetrical compound melts at 53° and boils at 277°; unsymmetrical diphenylethane is a liquid which boils at 286°. Oxidizing agents convert the former into benzoïc acid, and the latter into benzophenone.

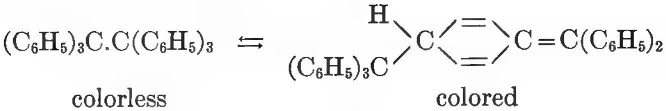
361. ***s*****-Tetraphenylethane**, $(C_6H_5)_2CH.CH(C_6H_5)_2$, is readily prepared by the action of zinc on a solution of diphenylbrommethane in ether or ethyl acetate: —

$$2(C_6H_5)CHBr + Zn = (C_6H_5)_2CH.CH(C_6H_5)_2 + ZnBr_2$$

The hydrocarbon is a stable compound which melts at 211°. It is oxidized by chromic acid to benzophenone $(C_6H_5)_2CO$. When passed through a red-hot tube the hydrocarbon loses hydrogen, and an unsaturated compound, tetraphenylethylene, $(C_6H_5)C=C(C_6H_5)_2$, is formed. Other hydrocarbons undergo a similar decomposition.

362. Hexaphenylethane, $(C_6H_5)_3C.C(C_6H_5)_3$. — A hydrocarbon to which this structure has been assigned is of great interest on account of its remarkable properties. When a solution of triphenylchlormethane in benzene or other solvent is treated with zinc, reaction takes place at room-temperature, and a hydrocarbon is obtained, which is characterized by its great activity. The reaction appears to be similar to that by which tetraphenylethane is formed from diphenylbrommethane, but the compound differs markedly in properties from the tetra-substitution-product. It unites directly with oxygen of the air, and is converted into a peroxide of the structure $(C_6H_5)_3C{-}O{-}O{-}C(C_6H_5)_3$: with iodine, triphenyliodomethane $(C_6H_5)_3CI$ is formed. The hydrocarbon forms more or less stable addition-products with many compounds, such as ketones, paraffin hydrocarbons, ethers, and so forth. On account of this unusual behavior, it was first thought that the hydrocarbon formed by the elimination of chlorine from triphenylchlormethane was a free radical, triphenylmethyl, $(C_6H_5)_3C-$. The determination of the molecular weight of the hydrocarbon in benzene as solvent, gave results which led to the conclusion that it was hexaphenylethane. These results are not conclusive, however, as so-called association often takes place in certain solutions, and, as a result, the molecular weights calculated from the lowering of the freezing-point are, at times, twice those assigned. For example, the molecular weights of alcohols, phenols, and acids determined in benzene, are often twice as great as the values determined by vapor-density methods.

Hexaphenylethane, or triphenylmethyl, as it is usually called, exists in two forms. One is colorless and the other is yellow. On solution, the colorless form passes into the colored variety. It is probable that the colorless compound is hexaphenylethane, and that before it enters into reaction it passes into its yellow isomer, which has a different structure. It has been suggested that the active isomer has a so-called quinoid (**491**) structure. It will be shown later that the quinones and substances related to them are colored. An explanation of the tautomerism in the case of hexaphenylethane is represented by the following formulas: —



According to this hypothesis colorless hexaphenylethane enters into reaction after first passing into the colored quinoid form. The hydrocarbon has been the subject of much investigation on account of its unusual properties and the fact that it suggests the possibility of a trivalent carbon atom.

363. Styrene, $C_6H_5.CH = CH_2$, phenylethylene, or styrole, derives its name from its occurrence in storax. It can be prepared by methods which are indicated by its structure. The hydrocarbon bears the same relation to cinnamic acid, $C_6H_5CH = CH_2COOH$, that benzoic acid bears to benzene. It can be prepared by heating sodium cinnamate with sodium hydroxide, or by simply distilling the free acid: —

$$C_6H_5.CH{:}CH.COOH = C_6H_5.CH{:}CH_2 + CO_2$$

The preparation of styrene from a saturated compound is analogous to that of ethylene and its derivatives. When ethylbenzene is treated with bromine, the first product of the reaction has the structure $C_6H_5.CHBr.CH_3$. This substance loses hydrogen bromide, when warmed with alcoholic potash: —

$$C_6H_5.CHBr.CH_3 + KOH = C_6H_5.CH{:}CH_2 + KBr + H_2O$$

Another method of preparation is similar to one used to prepare derivatives of ethylene. When phenylmethyl carbinol, which can be prepared by the Grignard synthesis, is heated with zinc chloride, styrene is formed: —

$$C_6H_5.CHOH.CH_3 = C_6H_5.CH{:}CH_2 + H_2O$$

Styrene is an oil, with an aromatic odor, which boils at 146°. It unites with the halogens and halogen hydrides, and polymerizes to metastyrene, $(C_8H_8)_x$, on heating. With nitric acid its behavior is unusual; the nitro compound formed contains the nitro group in the side-chain, $C_6H_5CH = CHNO_2$.

364. Stilbene $C_6H_5CH=CHC_6H_5$ (m.p. 124°), can be prepared in a number of ways, two of which are represented by the following equations: —

$$2C_6H_5CHCl_2 + Zn = C_6H_5CH{:}CHC_6H_5 + ZnC_2$$
$$2C_6H_5CH_3 + 2PbO = C_6H_5CH{:}CHC_6H_5 + 2Pb + 2H_2O$$

Zinc and benzal chloride react at ordinary temperatures. The preparation from toluene is effected by passing the vapor of the hydrocarbon over heated lead oxide. Stilbene reacts with the halogens and halogen acids and forms a crystalline compound with nitrogen peroxide, $(C_6H_5)_2C_2H_2.N_2O_4$.

365. *s*-**Tetraphenylethylene** $(C_6H_5)_2C = C(C_6H_5)_2$, is formed when a solution of benzophenone chloride is treated with zinc: —

$$(C_6H_5)_2CCl_2 + Zn = C_6H_5C{:}C(C_6H_5)_2 + ZnCl_2$$

It is most conveniently prepared by boiling a mixture of benzophenone chloride and diphenylmethane: —

$$(C_6H_5)_2CCl_2 + (C_6H_5)_2CH_2 = (C_6H_5)_2C{:}C(C_6H_5)_2 + 2HCl$$

The hydrocarbon does not show most of the properties characteristic of unsaturated compounds. It forms no addition-product with bromine or the halogen hydrides. When treated with bromine, substitution-products are obtained. It reacts with chlorine, however, to form the compound $(C_6H_5)_2CCl.-ClC(C_6H_5)_2$. The activity of compounds which contain a double bond is affected by the nature of the radicals in combination with the carbon atoms linked by this bond. No exact statement in regard to the phenomenon can be made at present. The subject has been investigated and warrants further study.

366. Phenylacetylene, $C_6H_5C \equiv CH$, can be prepared by the application of the methods used to prepare derivatives of acetylene. Acetophenone, $C_6H_5.CO.CH_3$, like other ketones, is converted into a chloride, $C_6H_5.CCl_2CH_3$, by phosphorus pentachloride. When heated with alcoholic potash, acetophenone chloride is converted into phenylacetylene: —

$$C_6H_5.CCl_2.CH_3 + 2KOH = C_6H_5C \equiv CH + 2KCl + 2H_2O$$

Phenylacetylene boils at 140°, and shows the properties characteristic of derivatives of acetylene; it unites with four atoms of bromine, and forms metallic derivatives.

367. Tolane, $C_6H_5C \equiv CC_6H_5$ (m.p. 60°), is formed by boiling stilbene bromide with alcoholic potash: —

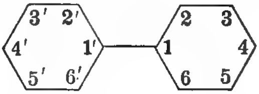
$$C_6H_5CHBr.CHBrC_6H_5 + 2KOH = C_6H_5C \equiv CC_6H_5 + 2KBr + 2H_2O$$

The hydrocarbon unites with halogens but does not form metallic derivatives. When heated with hydriodic acid and phosphorus it is reduced to stilbene.

368. Diphenyl, $C_6H_5.C_6H_5$, is formed, along with other hydrocarbons, when benzene is passed through a tube heated to redness, and by the action of sodium on an ethereal solution of brombenzene: —

$$2C_6H_5Br + 2Na = C_6H_5.C_6H_5 + 2NaBr$$

Diphenyl crystallizes from alcohol in large lustrous plates; it melts at 71° and boils at 254°. When treated with chlorine, bromine, nitric acid, or sulphuric acid substitution-products are formed. The possibility for isomerism among the derivatives of diphenyl, is greater than in the case of the homologues of benzene. In order to indicate the position of substituents the carbon atoms in diphenyl are numbered according to the following scheme: —



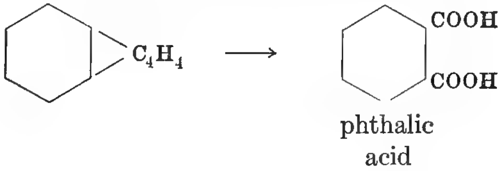
When diphenyl is brominated compounds of the following structures are formed, 4-bromdiphenyl, 4,4′-dibromdiphenyl; and when nitrated, 2-nitrodiphenyl, 4-nitrodiphenyl, 2,4′-dinitrodiphenyl, and 4,4′-dinitrodiphenyl. Higher substitution-products are also obtained. It is seen that the ortho and para positions are the ones taken by the entering group. In this respect the hydrocarbon resembles toluene.

Diphenyl is converted by active oxidizing agents into benzoic acid, $C_6H_5.COOH$. The structure of the substitution-products of the hydrocarbon is established by oxidation. The nitrodiphenyl which is converted into *p*-nitrobenzoic acid evidently has the nitro group in position 4. Substitution-products of diphenyl which contain the amino group are used in the manufacture of important dyes.

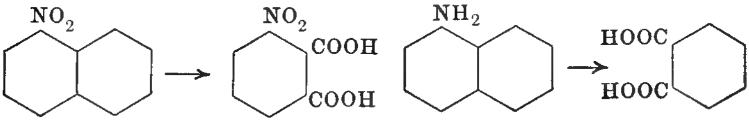
369. Naphthalene, $C_{10}H_8$, is present to the extent of about 5 per cent in coal-tar, from which it is obtained in large quantities. Naphthalene melts at 80° and boils at 218°. It is soluble in hot alcohol and in ether. It is very volatile, has a characteristic, penetrating odor, and is used extensively instead of camphor to protect woolen goods and furs from moths. The luminosity of coal gas is largely dependent on the naphthalene which it contains. The hydrocarbon is used to prepare compounds from which important dyes are manufactured.

Naphthalene is formed when the vapors of many compounds are passed through a red-hot tube. It can be synthesized by methods which lead to a definite view of its structure.

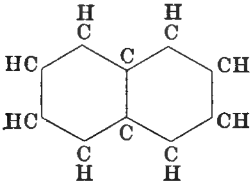
370. The *structure of naphthalene* has been determined by a study of the compounds formed as the result of the oxidation of the hydrocarbon and certain of its derivatives. When naphthalene is treated with active oxidizing agents it is converted into phthalic acid, a dibasic acid derived from benzene, in which the carboxyl groups have been shown to be in the ortho position. This fact indicates that naphthalene contains a benzene ring to which side chains are united in the ortho position: —



The configuration of the side-chain is determined in the following way: Nitronaphthalene is converted into nitrophthalic acid by oxidation. If the nitro group is reduced to the amino group, and the resulting aminonaphthalene is oxidized, phthalic acid is obtained. It is evident that, in the latter case, the oxidation destroys the ring to which the amino group is attached, and as phthalic acid is formed, it follows that the side-chain consists of a second benzene ring. The oxidation of the nitro and amino derivatives of naphthalene is expressed by the following formulas:

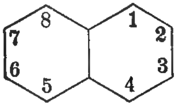


The difference between the action of oxidizing agents on the nitro derivative and the amino derivative is observed in the case of other compounds. Benzene derivatives which contain an amino group are readily decomposed by oxidizing agents, whereas rings which contain nitro groups are stable. The structure of napthalene is expressed by the formula, —



No entirely satisfactory formula for the hydrocarbon which takes into account the fourth bonds of the carbon atoms has been proposed.

371. Napthalene resembles benzene closely in its behavior with reagents. Substitution-products are formed when it is treated with chlorine, bromine, nitric acid, or sulphuric acid. The opportunities for isomerism are great owing to the presence of two rings. For reference, the carbon atoms are numbered as follows: —



Monosubstitution-products exist in two forms. The carbon atoms numbered 1, 4, 5, and 8 bear the same relation to the molecule. Compounds which contain a group in these positions are usually called α-compounds. The atoms numbered 2, 3, 6, and

7 are alike; substitution in one of these positions yields β-compounds. Ten disubstitution-products are possible in the case of compounds which contain two similar substituents; if the substituents are unlike, 14 disubstitution-products are possible. The structure of a compound is shown by prefixing to its name numbers indicative of the positions occupied by the substituents.

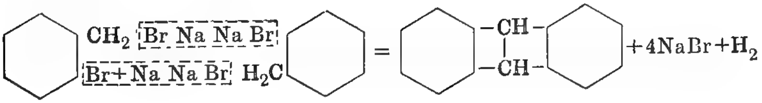
When chlorine is passed into boiling naphthalene α-chlornaphthalene is formed. The β-derivative is prepared by an indirect method. It will be recalled that when a substituent enters a benzene ring it takes a position ortho or para to the side-chain if this is a hydrocarbon radical. In the case of naphthalene the α-position in one ring is ortho to the other ring and the β-position is meta. It is thus clear why β-derivatives are not readily formed by direct substitution. Nitric acid converts naphthalene in the cold into α-nitronaphthalene. At higher temperatures dinitronapthalenes are formed which have the nitro groups in the 1, 8 and 1, 6-positions, the hydrogen atoms in the ortho position being replaced by the entering group.

372. Anthracene, $C_{14}H_{10}$, is obtained from coal-tar, in which it is present to the extent of less than 0.5 per cent. It is separated for use in the manufacture of alizarin, an important dye, which is commonly called Turkey red. Anthracene crystallizes in colorless plates, which show a blue fluorescence. It melts at 213°, and boils at 351°. It forms an addition-product with picric acid (trinitrophenol), of the formula

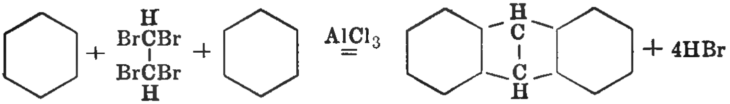
$$C_{14}H_{10}.(NO_2)_3C_6H_2OH,$$

which melts at 138°. Certain other hydrocarbons form addition-products with picric acid. The determination of the melting-points of these compounds is frequently made as an aid in the identification of such hydrocarbons.

373. The structure assigned to anthracene is arrived at as the result of a number of syntheses of the hydrocarbon. When *o*-brombenzyl bromide is heated with sodium, anthracene is formed: —

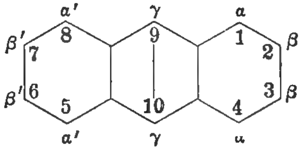


Anthracene may be prepared by the Friedel and Crafts synthesis from benzene and acetylene tetrabromide: —

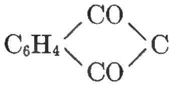


Other important syntheses lead to the same conclusion as to the structure of anthracene, and the reactions of the hydrocarbon can be interpreted on the basis of this view.

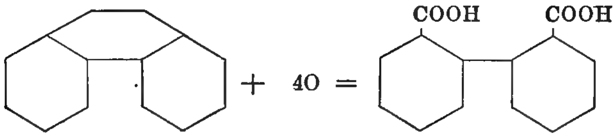
374. Anthracene is more reactive than benzene with reagents. It unites with two atoms of bromine at 0° and forms an addition-product, anthracene dibromide, which readily loses hydrobromic acid and passes into monobromanthracene. For reference, the carbon atoms of anthracene are numbered or indicated by Greek letters according to the following scheme: —



In anthracene dibromide the bromine atoms are united to the carbon atoms numbered 9 and 10. When anthracene is treated with bromine at higher temperatures, substitution-products which contain a number of halogen atoms are formed. Substitution takes place so readily with bromine that the reaction is conveniently used to prepare anhydrous hydrogen bromide, which is obtained by allowing bromine to fall, drop by drop, upon anthracene.

Anthracene yields sulphonic acids when treated with sulphuric acid. With nitric acid, however, nitro derivatives of the hydrocarbon are not formed. Anthracene is first oxidized to anthraquinone,  $C_6H_4\langle{CO \atop CO}\rangle C_6H_4$, which is converted into nitroanthraquinones if the acid used is concentrated or the mixture is heated. Oxidizing agents, in general, convert anthracene into anthraquinone, which crystallizes in light yellow needles, melting at 277°.

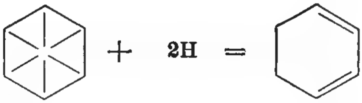
375. Phenanthrene, $C_{14}H_{10}$, is an isomer of anthracene with which it occurs in coal-tar. It crystallizes in colorless lustrous plates, which yield fluorescent solutions. It melts at 99° and boils at 340°. The hydrocarbon resembles anthracene in its reactions. Oxidizing agents convert it into phenanthraquinone, which on further oxidation yields diphenic acid, a dibasic acid derived from diphenyl. The formation of the latter is indicated by the following formulas: —



Phenanthrene Diphenic acid

Hydroaromatic Hydrocarbons

376. The hydrocarbons of this class may be formed by adding two, four, or six hydrogen atoms to the aromatic hydrocarbons. Hexahydrobenzene, hexahydrotoluene, and similar compounds, resemble the paraffins in chemical properties. This fact is in accord with the structure assigned to these hydrocarbons, which contain a ring of six saturated carbon atoms. Dihydrobenzene and tetrahydrobenzene, on the other hand, resemble closely the derivatives of ethylene. The addition of two or four hydrogen atoms to the benzene ring destroys the characteristic neutralization of the latent bonds of the six carbon atoms peculiar to aromatic compounds. In dihydrobenzene the carbon atoms appear to be joined in the manner in which they are joined in ethylene. This kind of union is expressed by a double bond. The change from benzene to dihydrobenzene may be expressed by the formulas, —



Only a brief description of a few hydroaromatic hydrocarbons will be given here.

377. Hexamethylene, C_6H_{12}, cyclohexane, or hexahydrobenzene, is found in Caucasian petroleum, which consists essentially of this hydrocarbon and its homologues, which are called napthenes. Hexamethylene is prepared by the method of Sebatier and Senderens, which consists in reducing a compound by passing a mixture of its vapor and hydrogen over finely divided nickel which is heated: —

$$C_6H_6 + 3H_2 = C_6H_{12}$$

Hexamethylene melts at 4.7° and boils at 81°. The hydrocarbon resembles methane in its behavior with halogens. It reacts energetically with chlorine in diffused light, and substitution-products are formed, from which chlorhexamethylene may be separated by fractional distillation. Hexamethylene, like hexane, is not readily attacked by sulphuric acid or nitric acid.

378. Menthane, $C_6H_{10}(CH_3)(i\text{-}C_3H_7)(1,\ 4)$, is hexahydrocymene. The hydrocarbon is of interest as many important compounds which occur in nature are derived from it. *Menthol*, the principal constituent of the oil of peppermint, is a derivative of menthan which contains a hydroxyl group in combination with the carbon atom ortho to the isopropyl radical.

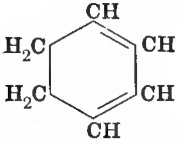
379. Cyclohexene, C_6H_{10}, tetrahydrobenzene, can be prepared by treating bromhexamethylene with alcoholic potash, the reaction being analogous to that by which hexene is prepared from hexyl bromide: —

$$C_6H_{11}Br + KOH = C_6H_{10} + KBr + H_2O$$

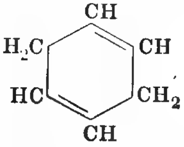
Cyclohexene decolorizes an aqueous solution of potassium permanganate and unites with bromine to form dibromhexamethylene: —

$$C_6H_{10} + Br_2 = C_6H_{10}Br_2$$

Cyclohexadiene, C_6H_8, dihydrobenzene, exists in two forms, the structures of which are represented by the formulas, —



Δ1,3-dihydrobenzene



Δ1,4-dihydrobenzene

The prefixes used in naming the compounds indicate the positions of the double bonds. The hydrocarbons are prepared by the elimination of two molecules of hydrogen chloride from the isomeric dichlorhexanes. They are characterized by great chemical activity. Δ1,3-Dihydrobenzene absorbs moisture from the air, unites directly with oxygen, forms a tetrabromide with bromine, and polymerizes on standing. It is interesting to note in this connection that the formula assigned to the active form of triphenylmethyl (**362**) contains a dihydrobenzene ring. Dihydrobenzene resembles in its activity certain hydrocarbons, called terpenes, which occur in nature. The terpenes and the compounds related to them will be considered later.

PROBLEMS

1. Write equations for reactions by which the following may be prepared from benzene by means of the Fittig synthesis: (*a*) $p\text{-}C_6H_4(C_2H_5)_2$, (*b*) $C_6H_5.CH_2CH = CH_2$, (*c*) $p\text{-}CH_3C_6H_4.C_6H_5$.

2. Write equations for reactions by which the following may be prepared by means of the Friedel and Crafts reaction: (*a*) $CH(C_6H_4CH_3)_3$, (*b*) $(C_6H_5)_2CO$ (*c*) $C_6H_5.C_3H_7$, (*d*) $C_6H_5.C_6H_4.CH_3$.

3. Write equations for reactions by which the following may be prepared by the Grignard synthesis: (*a*) $C_6H_5.CH = CH.CH_3$, (*b*) $C_6H_5.CH_3.C=CH_2$, (*c*) $C_6H_5.CH_2CH_3$, (*d*) $C_6H_5.C_6H_5$.

4. Write equations for reactions by which the following replacements may be effected: (*a*) SO_3H by H, (*b*) OH by H, (*c*) Br by H, (*d*) alkyl by H, (*e*) $=C=O$ by $=C=CHR$, (*f*)—CHO by $CH.R_2$, (*g*) halogen by alkyl.

5. Write the graphic formulas of all the isomeric dinitro substitution-products of (*a*) *o*-xylene, (*b*) *m*-xylene, and (*c*) *p*-xylene.

6. How could you distinguish by chemical means (*a*) C_6H_6 and C_6H_{14}, (*b*) $C_6H_5C_2H_5$ and $C_6H_4(CH_3)_2$, (*c*) $C_6H_5.CH_2CH_3$ and $C_6H_5CH=CH_2$, (*d*) $C_6H_5.CH_2OH$ and $C_6H_5.CH_3$?

7. An aromatic compound of the composition C_9H_{12} was converted into an acid of the composition $C_8H_6O_4$ when oxidized. Write the formulas of the two compounds.

8. An aromatic hydrocarbon of the formula $C_{13}H_{10}$ was converted by oxidation into a compound of the formula $C_{12}H_{19}O$. Write the formulas of the two compounds.

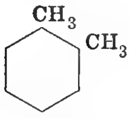
CHAPTER XX

DETERMINATION OF THE STRUCTURE OF AROMATIC COMPOUNDS, NITRO COMPOUNDS AND SULPHONIC ACIDS

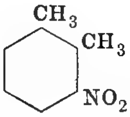
380. It has been stated that a number of isomeric derivatives of the aromatic compounds exist; from benzene can be obtained three dinitrobenzenes, three trinitrobenzenes, and so forth. It is well to indicate at the outset the general methods employed to determine the structure of such compounds, and thus avoid the frequent repetition which would result, if an attempt were made to state the arguments upon which the structure of each compound described is based.

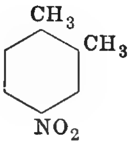
When a new compound is prepared its structure is determined by converting it into one of known constitution. Thus, if a hydrocarbon yields on oxidation phthalic acid, a dibasic acid derived from benzene by the replacement of two hydrogen atoms in the ortho position, the conclusion is drawn that the hydrocarbon contains two side-chains in the ortho position. Again, if a substitution-product of benzene is converted by simple reactions into metaxylene, the compound is considered to be a derivative of benzene in which the substituents occupy the meta position. The conclusions as to the structure reached in this way are based on two assumptions. It is assumed, first, that no deep-seated changes or molecular rearrangements take place in the transformations which are brought about, and the entering group takes the place of the group which it displaces; and, second, that the structure of the substance into which the new compound is converted is established. The first assumption is that upon which the determination of the structure of most organic compounds is based. It has been shown in the case of the aliphatic compounds that the assumption is a valid one in most cases, but that it leads to false conclusions at times. The same conclusion has been reached as a result of the study of aromatic compounds. A noteworthy example of a case in which the method fails is furnished by the three isomeric brombenzenesulphonic acids. The ortho, meta, and para compounds, when fused with sodium hydroxide, yield the same dihydroxy-derivative of benzene, resorcinol, which has been shown to be a meta compound. On account of such facts as this, a definite conclusion as to structure can not be reached by the study of a single transformation. The problem is not so difficult as it appears to be, on account of the fact that the exhaustive study of many transformations has shown clearly that those of certain types take place normally. Such transformations are the ones employed in the determination of structure.

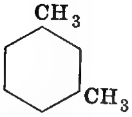
The method which has been sketched can be used only when the structures of certain reference-compounds are known. When the aromatic compounds were first studied it was necessary to establish by some absolute method the structure of a few compounds to which others might be referred. A number of ingenious methods were devised to solve this problem. But one of these, that of Körner, will be described here. The method is based on the determination of the number of mono-substitution-products which can be obtained from the compound, the structure of which is to be ascertained. The application of the method to disubstitution-products is well illustrated by the case of the three dimethylbenzenes (xylenes). The three hydrocarbons have the following melting-points and boiling-points: (I) m.p. – 28°, b.p. 142°; (II) m.p. – 54°, b.p. 139°; (III) m.p. 15°, b.p. 138°. Xylene (I) yields two mononitro derivatives, xylene (II) yields three, and xylene (III) yields but one such derivative. The facts lead to a definite conclusion as to the structure of the isomers. This will be seen from the following formulas: —



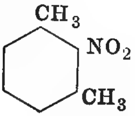
orthoxylene

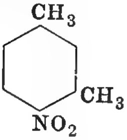


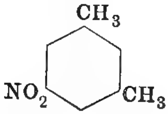


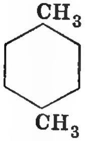


metaxylene

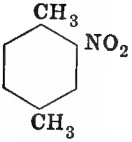








paraxylene

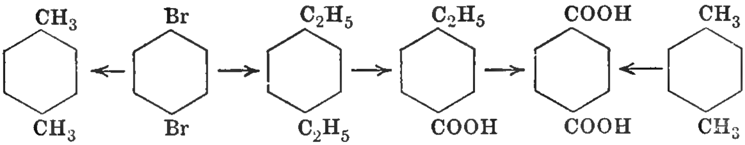


Two mononitroxylenes can be derived, theoretically, from orthoxylene, three from metaxylene, and but one from paraxylene. It follows, therefore, that the xylene boiling at 142°, from which two mononitro derivatives can be prepared, is orthoxylene, and that the ones boiling at 139° and 138° have the meta and para structure, respectively. The application of the so-called absolute method leads to the establishment of the structure of the three xylenes, which can serve, therefore, as reference-compounds. The three hydrocarbons yield three dibasic acids on oxidation; orthoxylene gives phthalic acid, metaxylene gives isophthalic acid, and paraxylene gives terephthalic acid. The three phthalic acids become, thus, reference-compounds. Other compounds can be readily converted into xylenes or phthalic acids, and can, therefore, be used in the determination of structure. Thus, the three dibrombenzenes can be converted into the three xylenes by Fittig's synthesis. The transformations establish the structure of the halogen derivatives. From these other compounds may be prepared. An example will be instructive. The dibrombenzene which melts at 89° is converted into paraxylene when treated with methyl iodide and sodium: —

$$C_6H_4Br_2 + 4Na + 2CH_3I = C_6H_4(CH_3)_2 + 2NaBr + 2NaI$$

The bromine derivative is, therefore, a para-compound. When it is treated with ethyl iodide and sodium, diethylbenzene is formed. This hydrocarbon on careful oxidation yields an ethylbenzoic acid. The diethylbenzene and ethylbenzoic acid prepared in this way are assumed to be para-compounds. The conclusion can be tested by oxidizing the ethylbenzoic acid.

As terephthalic acid, which has been shown to be a para-compound, is formed, the assumption that the ethylbenzoic acid belongs to this series is justified. The transformations which lead to the view of the structure of dibrombenzene, diethyl benzene, ethylbenzoic acid, and terephthalic acid are indicated by the following formulas. The conclusions rest upon the determination of the structure of paraxylene by the absolute method: —



The determination of structure by the absolute method has been applied to compounds other than the xylenes, among which are tri- and tetrasubstitution-products.

INFLUENCE OF THE NATURE OF THE RADICALS PRESENT IN A COMPOUND ON THE POSITION TAKEN BY SUBSTITUENTS

381. From a study of the structure of many substances formed as the result of the introduction of substituents into aromatic compounds, certain general conclusions of great importance can be drawn. It has been pointed out that aromatic compounds yield substitution-products when treated with sulphuric acid, nitric acid, chlorine, and bromine. Under certain conditions iodine can also be introduced directly. Alkyl, acyl, and other radicals can be introduced by means of the Friedel and Crafts synthesis. In all these cases the position in the molecule taken by the entering atom or group is determined by the nature of the atom or group already present. The facts established lead to the following rules: —

I. If the compound contains Cl, Br, I, NH_2, OH, or a hydrocarbon radical (CH_3, C_6H_5, and so forth), the entering atom or group, Cl, Br, I, SO_3H, NO_2, alkyl radical (CH_3) or acyl radical (CH_3CO) enters the positions para and ortho to the group already present. In general, the proportion of the para compound formed is greater than that of the ortho compound.

II. If the compound contains NO_2, SO_3H, CN, CHO, COOH, or COR, the entering atom or group takes the position meta to the group already present. At the same time a small proportion of the ortho and para compounds is also formed.

382. It should be noted that certain classes of compounds yield para and ortho compounds, and others yield principally meta compounds. The reason for this difference is not altogether clear. It is seen, however, that the substituents which caused the entering group to take the meta position, are what have been called negative groups. Whereas among those which cause the entering group to take the para position are both positive and negative groups. This fact appears to be somewhat anomalous, as we should expect a chlorine atom to resemble in its directing influence the CN radical, for example, rather than the positive amino group. That the positive or negative nature of the directing atom or group is an important factor in its influence is clear, however. In general, those atoms or groups which form acids when in combination with hydroxyl, cause the entering group to substitute largely in the meta position. The groups mentioned above which exert this influence, form acids when in combination with hydroxyl. On the other hand, the groups which send an entering group to the para position do not form acids when in combination with hydroxyl, except the halogens and the radicals derived from aromatic hydrocarbons, such as phenyl, tolyl, and so forth, which are called *aryl* radicals. It is of interest to note, however, that the hydroxyl derivatives of the halogens and of aryl radicals are very weak acids. Hypochlorous acid, $Cl-OH$, and phenol, C_6H_5OH, are weaker than carbonic acid; they do not decompose carbonates, and are set free from their salts by carbonic acid. One side of the chemical nature of chlorine is shown by this fact. From this point of view, the difference between the directing influence of chlorine and the nitro group can be understood.

It is important that the student should master at this point the conclusions in regard to the effect of the groups on each other which are summarized in the two general statements given above, and he should constantly apply them in the study of the compounds to be described later.

NITRO COMPOUNDS

383. The nitro derivatives of the aromatic compounds are prepared by the action of nitric acid on the hydrocarbons or their substitution-products. The process is called nitration. The ease with which reaction takes place is determined by the nature of the element or group in combination with the benzene ring. In general, it is more difficult to nitrate a compound which contains a strongly negative substituent than one which contains alkyl, hydroxyl, or amino groups. For example, benzoic acid, $C_6H_5.COOH$, must be heated with either fuming nitric acid, or a mixture of concentrated nitric acid and sulphuric acid, in order to convert it into nitrobenzoic acid. On the other hand, phenol, C_6H_5OH, can be nitrated by allowing it to react at ordinary temperatures with concentrated nitric acid diluted with twice its volume of water.

The number of nitro groups introduced is determined by the strength of the acid used, and the temperature at which the reaction is carried out. As the number of these groups increases the difficulty of further nitration also increases.

Hydrocarbons are usually nitrated by treating them with a mixture of concentrated nitric and sulphuric acids. As the reaction involves the formation of water,

$$C_6H_6 + HNO_3 = C_6H_5NO_2 + H_2O$$

the acid becomes more and more dilute as the nitro compound is formed, and finally ceases to act. This difficulty is overcome by adding to the mixture concentrated sulphuric acid, which unites with the water formed, and thus prevents the dilution of the nitric acid.

The nitro derivatives of benzene and its homologues are pale yellow liquids which distil without decomposition, or colorless or yellow solids, which crystallize well. They are heavier than water, in which they are insoluble. They are soluble in alcohol and in ether. Solid nitro compounds are often prepared, and their melting-points determined, as an aid in the identification of other substances.

Nitro derivatives of certain aromatic hydrocarbons are manufactured commercially in large quantities, and are used in the preparation of amines which are converted into a great variety of dyes.

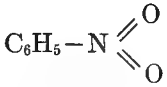
384. Reactions of Nitro Compounds.— Nitro compounds are reduced to amines by nascent hydrogen in acid solution: —

$$C_6H_5NO_2 + 6H = C_6H_5NH_2 + 2H_2O$$

In the laboratory the reduction is usually effected by treating the nitro compound with tin and hydrochloric acid. In alkaline solution nitro compounds are reduced to azoxy-, azo-, and hydrazo-compounds, which will be described later (**424**).

Nitro derivatives are, in general, stable compounds, from which the nitrogen is removed with difficulty. The accumulation of nitro groups, however, has a marked effect on the reactivity of the nitro groups or the other atoms or groups which the compound contains.

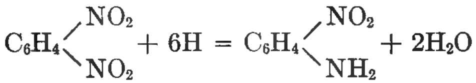
The fact that nitro compounds are converted by reduction into amines is evidence that in the nitro compounds the nitrogen atom is joined to the ring. The structure of nitrobenzene is, accordingly,



385. Nitrobenzene, $C_6H_5NO_2$, is a yellow liquid, which has an odor resembling that of the oil of bitter almonds; it boils at 210°, melts at 3°, and has the specific gravity 1.204 at $\frac{20°}{4°}$. It is manufactured in large quantities by allowing a mixture of nitric acid and sulphuric acid to flow slowly into benzene which is kept cool and thoroughly stirred. Nitrobenzene is converted into aniline, $C_6H_5NH_2$, by nascent hydrogen. It is soluble in concentrated sulphuric acid, and is precipitated unchanged when the solution is diluted with water.

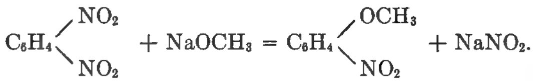
386. Dinitrobenzenes, $C_6H_4(NO_2)_2$, are formed when benzene is heated with a mixture of nitric acid and sulphuric acid. The chief product of the reaction is *m*-dinitrobenzene, which crystallizes from alcohol in colorless needles, melts at 91°, and boils at 297°. *o*-Dinitrobenzene and *p*-dinitrobenzene, which melt at 118° and 172°, respectively, are also formed in small quantities.

The three dinitrobenzenes yield diamines, $C_6H_4(NH_2)_2$, when reduced by the hydrogen generated by the action of an acid on a metal. Under certain conditions, which will be discussed later (**511**), but one nitro group can be reduced. In this way nitro-anilines may be prepared: —



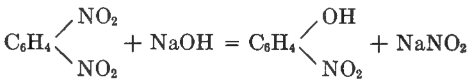
$$C_6H_4\begin{matrix}\diagup NO_2\\ \diagdown NO_2\end{matrix} + 6H = C_6H_4\begin{matrix}\diagup NO_2\\ \diagdown NH_2\end{matrix} + 2H_2O$$

The introduction of a second nitro group into nitrobenzene increases the reactivity of the compound with various reagents. The position occupied by the second group has a marked effect on the reactivity of the resulting compound. The nitro groups in *m*-dinitrobenzene are firmly bound to the ring, and, as a consequence, are not readily removed by reagents. The hydrogen atom situated between the two nitro groups is, however, rendered more active, as it is oxidized to a hydroxyl group when *m*-dinitrobenzene is treated with potassium ferricyanide. The compound formed is 2,6,-dinitrophenol. One of the nitro groups in *o*-dinitrobenzene and in *p*-dinitrobenzene can be removed by certain reagents. Both compounds are converted into ethers when treated with sodium methylate: —

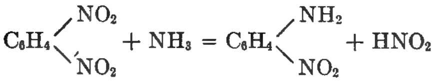


$$C_6H_4\begin{matrix}\diagup NO_2\\ \diagdown NO_2\end{matrix} + NaOCH_3 = C_6H_4\begin{matrix}\diagup OCH_3\\ \diagdown NO_2\end{matrix} + NaNO_2.$$

The ortho compound is more reactive than the para compound. When the former is boiled with a solution of sodium hydroxide, one nitro group is replaced by hydroxyl, and when heated with an alcoholic solution of ammonia, by the amino group: —



$$C_6H_4\begin{matrix}\diagup NO_2\\ \diagdown NO_2\end{matrix} + NaOH = C_6H_4\begin{matrix}\diagup OH\\ \diagdown NO_2\end{matrix} + NaNO_2$$



$$C_6H_4\begin{matrix}\diagup NO_2\\ \diagdown NO_2\end{matrix} + NH_3 = C_6H_4\begin{matrix}\diagup NH_2\\ \diagdown NO_2\end{matrix} + HNO_2$$

Similar reactions are observed in other cases. In general, the influence of a group on a second group decreases as we pass from the ortho to the para to the meta positions, the effect of a group in the ortho position being much greater than that of a group in the other positions.

387. **Nitrotoluenes**, $C_6H_4(CH_3)(NO_2)$, are formed when toluene is nitrated. The resulting product consists of *p*-nitro-

toluene, (m.p. 54°, b.p. 234°) and *o*-nitrotoluene, (m.p. 10.5°, b.p. 218°) with a very small proportion of the meta-compound (m.p. 16°, b.p. 230°). The relation between the amounts of each formed is determined by the temperature at which the nitration is effected. In general, the temperature has an appreciable effect on the position taken by an entering group, when substitution is effected.

388. Nitrostyrene, $C_6H_5CH{=}CHNO_2$, contains the nitro group in the side-chain. It is prepared by the action of nitric acid on styrene, the reaction being an example of the few cases in which a nitro group is introduced into a side-chain by direct nitration. The nitrostyrenes in which the substituent is situated in the ring, are prepared from compounds into which the nitro group has been introduced before the double bond is established.

389. *o*-Nitrophenylacetylene, $NO_2C_6H_4.C{\equiv}CH$, is prepared by boiling *o*-nitrophenylpropiolic acid with water: —

$$NO_2C_6H_4.C{\equiv}C.COOH = NO_2C_6H_4.C{\equiv}CH + CO_2$$

The method of preparation is illustrative of the methods usually employed to prepare derivatives of hydrocarbons which contain unsaturated side-chains. The derivatives are usually not prepared directly from the hydrocarbons, as in the case of benzene and its homologues, but a saturated compound which contains the substituent in the desired position is first formed, and then converted into an unsaturated compound by the usual methods.

390. *α*-Nitronaphthalene, $C_{10}H_7.NO_2$, is formed as the result of the direct nitration of naphthalene. It crystallizes in yellow prisms, which melt at 61°. The *β*-compound, which melts at 79°, is prepared by an indirect method.

391. Identification of Nitro Compounds. — The definite identification of a substance as a nitro compound is difficult, as substances exist which are closely related to nitro compounds and show many of the reactions of the latter. Nitro compounds are insoluble in water, but dissolve in many organic solvents. They are, in general, soluble without decomposition in concentrated sulphuric acid, and are precipitated when the solution is poured into water. The specific gravity of nitro compounds is greater than one. When treated with tin and hydrochloric acid, they are reduced to amines. This reaction serves as a valuable test. The nitro compound, which is insoluble in hydrochloric acid, is converted into a salt of an amine, which is soluble. A mixture of stannous chloride and hydrochloric acid may be used conveniently in making the test, as nitro compounds are reduced by this reagent. When a nitro compound is warmed with stannous chloride and hydrochloric acid, it passes into solution slowly, owing to the formation of the hydrochloride of the amine:

$$C_6H_5NO_2 + 3SnCl_2 + 7HCl = C_6H_5NH_2.HCl + 3SnCl_4 + 2H_2O$$

The amine is liberated from its salt by treating the solution with an excess of sodium hydroxide, and may be obtained by extracting with ether or distilling with steam.

It should be noted that nitro compounds containing other groups often possess properties which are not characteristic of simple nitro compounds. For example, nitrobenzene is insoluble in a solution of sodium hydroxide, but nitrophenol, $NO_2.C_6H_4.OH$, is soluble in this reagent. The difficulties met with in the identification of such compounds is, consequently, greater than that encountered in the case of substances which contain but one kind of substituent.

SULPHONIC ACIDS

392. Sulphonic acids are prepared by the action of concentrated sulphuric acid on aromatic compounds: —

$$C_6H_6 + H_2SO_4 = C_6H_5.SO_3H + H_2O$$

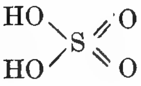
When sulphonation takes place with difficulty, it is necessary to use a mixture of sulphuric acid and sulphur trioxide, the proportion of the latter being determined by the difficulty with which the sulphonic acid group is introduced. The nature of the substituent in the benzene ring affects markedly the ease with which sulphonation is effected. The statement made in connection with the nitro compounds applies to sulphonation as well as to nitration.

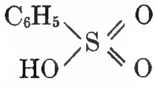
The sulphonic acids are solids that crystallize from water, in which many are readily soluble. In order to isolate them they must be separated from the excess of sulphuric acid present in the mixture obtained as the result of sulphonation. This can be done in a number of ways. The simplest method, which is applicable in a number of cases, is to pour the mixture into concentrated hydrochloric acid. Many sulphonic acids which are readily soluble in water, dissolve with difficulty in concentrated hydrochloric acid. The precipitate formed is filtered off, washed with hydrochloric acid until free from sulphuric acid, and finally crystallized from water. If the sulphonic acid is difficultly soluble in water, it is separated from the excess of sulphuric acid by pouring the product of the reaction into ice-water.

Oftentimes it is advisable to isolate the sulphonic acid as a salt. One way of doing this is to pour slowly the mixture of sulphonic acid and sulphuric acid into a saturated solution of sodium chloride, which is kept cold. The sodium salt of the sulphonic acid separates, owing to its insolubility in a solution of sodium chloride. The salts prepared in this way always are contaminated by sodium chloride.

A second method of isolating a salt of the acid, which is applicable in all cases, is based on the facts that the barium salts of sulphonic acids are soluble in water, whereas barium sulphate is insoluble. The mixture of sulphuric acid and sulphonic acid is diluted with water, and neutralized with barium carbonate. The solution is then heated and filtered. On evaporation the barium salt of the sulphonic acid is obtained. The free acid may be prepared by adding to a solution of the barium salt the amount of sulphuric acid required to precipitate the barium as sulphate.

393. Reactions of Sulphonic Acids. — The sulphonic acids are strong acids, and resemble sulphuric acid in many of their properties. They are considered as derived from sulphuric acid by the replacement of a hydroxyl group by radicals: —





The reactions of sulphonic acids are in accord with this view of their structure. When subjected to the action of active reducing agents they are converted into mercaptans, in which the sulphur is joined to carbon: —

$$C_6H_5.SO_3H \xrightarrow{H} C_6H_5.SH$$

Sulphonic acids react with alcohols to form esters,—

$$C_6H_5SO_2.OH + C_2H_5OH = C_6H_5SO_2.OC_2H_5 + H_2O$$

which show the chemical properties characteristic of other esters.

When treated with phosphorus pentachloride, sulphonic acids or their salts are converted into acid chlorides: —

$$C_6H_5SO_2OH + PCl_5 = C_6H_5SO_2Cl + POCl_3 + HCl$$

When heated under pressure with water, the sulphonic acid group is eliminated and hydrocarbons are formed: —

$$CH_3.C_6H_4.SO_3H + HOH = CH_3.C_6H_5 + H_2SO_4$$

The salts of sulphonic acids are frequently used in the preparation of other compounds, as the sulphonic acid group can be replaced by other groups. When fused with sodium or potassium hydroxide, the salts of sulphonic acids are converted into the salts of phenols: —

$$C_6H_5SO_3K + 2KOH = C_6H_5OK + K_2SO_3$$

The free phenols are obtained by adding acid to the product of the reaction: —

$$C_6H_5OK + HCl = C_6H_5OH + KCl$$

This reaction, which furnishes a convenient way of converting a hydrocarbon into its hydroxyl derivative, is used in the industrial preparation of phenol and analogous compounds.

When a salt of a sulphonic acid is distilled with potassium cyanide, a nitrile is formed: —

$$C_6H_5SO_3K + KCN = C_6H_5CN + K_2SO_3$$

This reaction furnishes a means of preparing cyanides, from which acids are obtained by hydrolysis.

394. Benzenesulphonic Acid, $C_6H_5SO_3H.1\frac{1}{2}H_2O$, forms deliquescent crystals, which are very soluble in water, and melt at 42°. The acid can be converted into phenol, C_6H_5OH, benzonitrile, C_6H_5CN, and benzenesulphonyl chloride, $C_6H_5SO_2Cl$, as described above.

395. **Benzenesulphonyl Chloride**, $C_6H_5SO_2Cl$, which is also called benzenesulphon chloride or benzenesulphonic chloride, is an oil, insoluble in water, which possesses a characteristic odor. It boils with decomposition at 247° but distils unchanged at 120° under a pressure of 10 mm. It solidifies in a freezing mixture to crystals which melt at 14.5°. The compound possesses the chemical properties which are characteristic of acyl chlorides. It is decomposed slowly by hot water, reacts with alcohols to form esters, and with ammonia and amines to form amides.

Benzenesulphonyl chloride is a useful reagent to distinguish between the three classes of amines. The method was first described by Hinsberg. When a primary amine is treated with the chloride in the presence of sodium hydroxide, a substituted sulphonamide is formed: —

$$C_6H_5SO_2Cl + CH_3NH_2 = C_6H_5SO_2.NHCH_3 + HCl$$

The compound is soluble in sodium hydroxide, as the strongly negative $C_6H_5SO_2$ group makes it possible to replace the hydrogen atom linked to nitrogen: —

$$C_6H_5SO_2NHCH_3 + NaOH = C_6H_5SO_2NNaCH_3 + H_2O$$

An amide is formed also when the chloride reacts with a secondary amine, —

$$C_6H_5SO_2Cl + (CH_3)_2NH = C_6H_5SO_2.N(CH_3)_2 + HCl$$

but the resulting product is not soluble in alkalies as it contains no hydrogen atom which can be replaced by a metallic atom. Tertiary amines do not react with benzenesulphonyl chloride. It is thus possible to separate and distinguish from one another the three classes of amines.

396. **Benzenesulphonamide**, $C_6H_5SO_2NH_2$, is formed by the action of ammonia on benzenesulphonyl chloride. It crystallizes from hot water in needles, which melt at 156°. It shows the chemical properties characteristic of amides. On account of the presence of the strongly negative $C_6H_5SO_2$ group, the amide dissolves in aqueous solutions of alkalies.

The amides prepared from sulphonic acids crystallize well from hot water, and possess well defined melting-points. They are, as a consequence, of service in effecting the identification of sulphonic acids.

397. Toluenesulphonic Acids, $CH_3C_6H_4.SO_3H$. — The product of the reaction between toluene and sulphuric acid consists almost entirely of a mixture of the para and ortho acids. The relation between the amounts of the two acids formed is affected by the temperature at which the reaction is carried out. When a mixture of sulphuric acid and toluene is heated on a water-bath, the chief product is the para acid. When the mixture is kept at room temperature and stirred vigorously the percentage of the ortho compound formed is largely increased.

398. Naphthalenesulphonic Acids, $C_{10}H_7.SO_3H$. — The effect of the temperature at which sulphonation is carried out on the position taken by the entering group, is well shown in the case of naphthalene. When the hydrocarbon is heated with concentrated sulphuric acid at 80°, the chief product of the reaction is the α-acid; at 160° the β-acid is chiefly formed. The acids form hygroscopic crystals. They are prepared in large quantities in the manufacture of the naphthols and the naphthylamines.

399. Identification of Sulphonic Acids. — In order to determine whether a substance which contains sulphur is a sulphonic acid or a salt of a sulphonic acid, it is fused with potassium hydroxide for a short time, care being taken to avoid heating to a higher temperature than is necessary to fuse the alkali. The product is next dissolved in water, and a slight excess of dilute acid is added. If the substance used is a sulphonic acid, a phenol and sulphur dioxide are formed. The presence of a phenol in solution can be determined by adding bromine water, as phenols are converted into insoluble bromine substitution-products when treated with an aqueous solution of the halogen. The presence of sulphur dioxide, which is formed from the sulphite produced as the result of the fusion with the alkali, can be detected by its odor.

If the compound proves to be a sulphonic acid, its identification is completed by converting it into a sulphonamide, the melting-point of which is determined. The acid or salt is treated with phosphorus pentachloride, and the resulting sulphonyl chloride, after washing with water, converted into the amide by allowing it to stand for a short time with ammonia. The amide is finally crystallized from hot water.

PROBLEMS

1. Two hydrocarbons of the formula C_9H_{12} were studied. It was found that one yielded two and the other three mononitro derivatives. Write the structural formulas of the two hydrocarbons.

2. Write the structural formula of a hydrocarbon $C_{10}H_{14}$, which yielded but one mononitro compound, and was converted by oxidation into an acid of the formula $C_8H_6O_4$.

3. Write the structural formula of a hydrocarbon $C_{10}H_{14}$, which yielded two mononitro derivatives, and was converted by oxidation into the acid $C_8H_6O_4$.

4. Applying the rules for substitution in aromatic compounds, write the structural formulas of products formed by (*a*) the nitration of toluene, (*b*) the bromination of benzene, (*c*) the sulphonation of $C_6H_5.COOH$, (*d*) the compound formed from chlorbenzene and methyl chloride by the Friedel and Crafts reaction, (*e*) the bromination of nitrobenzene, (*f*) the nitration of brombenzene, (*g*) nitration of $C_6H_5.CHO$.

5. Show how by the use of solvents a mixture of the following substances may be separated into its components: C_6H_6, C_6H_5COOH, and $C_6H_5NO_2$.

6. The calcium salts of the sulphonic acids are soluble in water. Devise a means of obtaining pure benzenesulphonic acid from a mixture of the acid and sulphuric acid.

CHAPTER XXI

HALOGEN DERIVATIVES OF AROMATIC HYDROCARBONS

400. It will be recalled that the halogen substitution-products of the aliphatic compounds are prepared, in general, from oxygen derivatives or from unsaturated compounds. While halogen derivatives are also formed as the result of the substitution of halogen for hydrogen by the direct action of chlorine or bromine, the preparation of compounds in this way is effected most conveniently in a comparatively few cases only. The most generally applicable method of preparing halogen derivatives of the aromatic compounds, however, is by the action of the free halogen on hydrocarbons or their substitution-products.

Many aromatic compounds like toluene, xylene, benzyl alcohol, $C_6H_5.CH_2OH$, and so forth, contain, in addition to a benzene ring, a radical related to the aliphatic compounds. The methods employed to introduce halogen into these side-chains are the same as those used in the case of the derivatives of methane. Benzyl alcohol, $C_6H_5.CH_2OH$, for example, may be considered as a substitution-product of methyl alcohol formed as the result of the replacement of one hydrogen atom by the phenyl radical. The hydroxyl group which it contains is linked to a methane carbon atom. In order to replace the hydroxyl group by bromine, the method used is that by which methyl alcohol is converted into methyl bromide, namely, the treatment of the alcohol with hydrobromic acid. In phenol, $C_6H_5.OH$, on the other hand, the hydroxyl group is linked to a carbon atom in the benzene ring and, as a consequence, is not replaced by bromine when phenol is treated with hydrobromic acid. It should be noted, therefore, that the selection of the method to be used to introduce halogen atoms into an aromatic compound is determined by the place in the molecule which the atom is to enter. If the halogen is to be introduced into the side-chain, the various methods described under aliphatic halogen derivatives may be used; if it is to be introduced into the ring, the methods about to be considered should be used.

Substitution of hydrogen in the benzene ring is readily effected by chlorine or bromine. The ease with which reaction takes place is determined by the nature of the group present in the compound. In general, the effect of the various groups on the introduction of halogen is the same as that mentioned in the case of nitration. For example, phenol, C_6H_5OH, and aniline, $C_6H_5NH_2$, are converted into bromine substitution-products when treated with an aqueous solution of the halogen. In the case of hydrocarbons and compounds which contain strongly negative groups the introduction of halogen is much facilitated by the presence of a carrier. Iron or iodine are most frequently used for this purpose.

The position taken by halogen atoms in the derivatives of benzene which contain alkyl radicals as side-chains, is markedly affected by the conditions under which the reaction takes place. At low temperatures, if reaction takes place, the halogen replaces the hydrogen atoms in the ring. When, however, chlorine or bromine is passed into the boiling hydrocarbon, the halogen enters the side-chain. In the presence of a halogen-carrier substitution takes place almost exclusively in the ring, or nucleus, as it is sometimes called. The effect of sunlight on the reaction is also marked. It will be recalled that sunlight facilitated greatly the replacement of hydrogen by halogen in aliphatic compounds. A similar effect is observed in the case of aromatic compounds which contain aliphatic side-chains. Even at 0° chlorine or bromine enters the side-chain when the reaction takes place in the sunlight.

The principles which have just been stated are of great importance. They are emphasized by the following example. When a mixture of toluene and bromine is allowed to stand at a low temperature in the dark, substitution takes place slowly and *p*-bromtoluene and *o*-bromtoluene, $C_6H_4Br.CH_3$, are formed. When, however, bromine is added to boiling toluene, substitution in the side-chain takes place and compounds of the formulas $C_6H_5.CH_2Br$, $C_6H_5.CHBr_2$, and $C_6H_5.CBr_3$, are formed. The presence of a carrier increases the rate at which substitution in the ring takes place.

Iodine can be introduced into aromatic compounds by the action of the free halogen, if the reaction is carried out under conditions which bring about the removal of the hydriodic acid formed as the result of the substitution. For example, iodobenzene is formed when benzene is heated with iodine and mercuric oxide, iodic acid, or other substances which react with hydriodic acid. Reactions of this kind are not used, however, as a means of preparing iodo derivatives. Free iodine also converts aniline, $C_6H_5.NH_2$, into substitution-products. In this case the hydriodic acid formed is removed as the result of the formation of a salt of aniline, $C_6H_5NH_2.HI$.

Halogen derivatives of aromatic compounds may also be prepared from hydroxyl derivatives by a reaction which is analogous to that used in the case of aliphatic compounds. When phenol, C_6H_5OH, and similar substances are treated with the halides of phosphorus, the hydroxyl groups are replaced by halogen. The yield of halogen compound is small in most cases, however, and the reaction is seldom used as a means of preparing such compounds. When the hydroxyl group is situated in a side-chain, the reaction takes place, in the main, as in the case of aliphatic compounds.

Halogen derivatives which contain the halogen in the ring are conveniently prepared from amino compounds. The method of preparation, which is an important one on account of its wide applicability, will be described in detail later (**429**). It involves the conversion of an amine, for example, aniline, $C_6H_5NH_2$ into a diazo compound, $C_6H_5N_2Cl$, which, when heated with the halogen hydrides or certain of their salts, undergoes decomposition with the formation of a halogen derivative. The following equation expresses such a decomposition: —

$$C_6H_5N_2Cl + KI = C_6H_5I + N_2 + KCl$$

In this way the NH_2 group may be replaced by chlorine, bromine, or iodine. As amino compounds are readily prepared from nitro compounds, which, in turn, are formed by the action of nitric acid on hydrocarbons, the reaction serves as a means of introducing halogen atoms into hydrocarbons. Although a number of steps are involved in the process, it is often used in the preparation of halogen derivatives. It is of particular value in the preparation of iodo compounds and of halogen derivatives which cannot be prepared by the direct action of halogens on hydrocarbons. The use of the diazo reaction in the preparation of halogen compounds will be illustrated by typical examples later.

The number of halogen atoms introduced into the ring by direct chlorination or bromination is determined by the amount of the halogen used, and the temperature at which the reaction is carried out. The position taken by the entering atom is determined by the nature of the groups present. The conclusions which have been arrived at as the result of the study of many compounds, have been summarized in the rules which have been given (**381**).

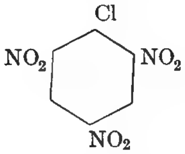
The halogen derivatives of the aromatic hydrocarbons are liquids or solids of comparatively high boiling-points. Those in which the substituent is in the ring have faint, agreeable odors, while those which contain halogen atoms in the side-chain have generally a pungent odor. In many cases they cause a copious flow of tears. The acyl halides derived from the aromatic acids resemble in properties the halides of the fatty acids. They will be discussed in connection with the acids.

401. Reactions of Aromatic Halogen Compounds. — The ability of a halogen atom in an aromatic compound to react with other substances, is dependent upon its position in the molecule and upon the nature and the relative position of the other atoms or groups present. Halogen atoms in side-chains show the reactions which are characteristic of aliphatic compounds. Thus benzyl chloride, $C_6H_5.CH_2Cl$, can be converted by water into benzyl alcohol, $C_6H_5.CH_2OH$, by potassium sulphite into a sulphonic acid, $C_6H_5CH_2.SO_3H$, and so forth. Halogen atoms in the nucleus, in general, do not enter into reaction readily. Chlorbenzene, for example, is not affected by boiling alkalies, acid sulphites, potassium cyanide, ammonia, and many of the other substances which react with aliphatic halogen compounds. The halogen atoms in chlorbenzene and similar compounds are removed by sodium, however. The formation of diphenyl from brombenzene has already been noted: —

$$2C_6H_5Br + 2Na = C_6H_5.C_5H_5 + 2NaBr$$

Magnesium also reacts with halogen compounds in which the halogen atom is in the ring. Brombenzene and the metal yield the compound C_6H_5MgBr, which can be used in the preparation of a large number of substances by Grignard's method.

The accumulation of negative groups in a halogen compound results in an increased activity of the halogen atom. This is especially noticeable in the case of the compounds in which two nitro groups are situated in the positions ortho to a halogen atom. The trinitrochlorbenzene of the structure, —



for example, reacts readily with hot water, and the halogen atom is replaced by a hydroxyl group. The compound resembles in many of its reactions the acyl chlorides.

402. Identification of Aromatic Halogen Compounds. — The methods of identifying these compounds are similar to those described under the aliphatic compounds. It is often possible to determine whether the halogen present is in the ring or in the side-chain, by boiling the substance to be tested with an alcoholic solution of potassium hydroxide. If no reaction takes place it can be assumed that the halogen atom present is in combination with a carbon atom in the ring. In order to determine whether or not reaction has taken place, the product is poured into water, acidified with nitric acid, and silver nitrate is added. The formation of a precipitate of a silver halide shows that the halogen has been removed from the organic compound.

The chlorides derived from the aromatic acids, of which benzoyl chloride, $C_6H_5.COCl$, is an example, do not react rapidly with water. They are readily converted into salts when shaken with a solution of an alkali, and into esters when shaken with ethyl alcohol and a solution of sodium hydroxide. The identification of acyl chlorides is best effected by converting them into amides by the action of ammonia: —

$$C_6H_5COCl + NH_3 = C_6H_5CONH_2 + HCl.$$

A few typical halogen substitution-products will now be described briefly.

403. Brombenzene, C_6H_5Br, is prepared by the action of bromine on benzene. It is a colorless liquid which boils at 156°, and has the specific gravity 1.491 at 20°. The effect of a halogen-carrier on the rate at which substitution takes place can be readily shown by treating two samples of benzene with bromine and adding to one a small amount of aluminium or powdered iron. No appreciable reaction takes place for a long time in the mixture which does not contain the carrier. In the presence of the metal, however, substitution soon takes place and hydrobromic acid is rapidly evolved. If the mixture of bromine and benzene which contains a carrier is heated, some dibrombenzene is formed, although the amount of the halogen used is that which corresponds to the amount required for the introduction of a single halogen atom. Even when the greatest precautions are taken, it is impossible to exclude the formation of the disubstitution-product. The latter can be partially separated from brombenzene by distillation with steam, with which brombenzene is more volatile than dibrombenzene. The substance is finally purified by fractional distillation.

404. Dibrombenzenes, $C_6H_4Br_2$. — When two bromine atoms are introduced into benzene by direct substitution, the chief product of the reaction is the para compound, which melts at 89° and boils at 219°. A small amount of the ortho compound is also obtained; this melts at $-1°$ and boils at 224°. *m*-Dibrombenzene is most conveniently made by an application of the diazo reaction (**429**). The most readily prepared dinitrobenzene is a meta compound, on account of the fact that a nitro groups directs an entering group to the meta position. For this reason, nitro compounds are much used in the preparation of substitution-products which contain substituents in the meta positions. Nitro compounds can be readily reduced to amines, and these, in turn, can be converted into halogen compounds by replacing the amino group by means of the diazo reaction. *m*-Dibrombenzene is an oil which boils at 219°. The structure of the dibrombenzenes has been determined by converting them into the xylenes, which, it has been pointed out, serve as reference-compounds.

All the possible bromine substitution-products of benzene are known. Hexabrombenzene, C_6Br_6, is formed by the action of bromine on benzene in the presence of iodine at 250°–400°. It is a solid which melts at about 315°.

405. Iodobenzene, C_6H_5I, is most readily prepared from aniline, $C_6H_5NH_2$, by the diazo reaction. It boils at 185°. The compound, like other aromatic iodo derivatives, enters into reactions which are not shown by halogen derivatives which contain chlorine or bromine. These reactions result from the fact that iodine can form stable compounds in which the valence of the halogen is greater than one. It will be recalled that when iodine is treated with chlorine, iodine trichloride, ICl_3, is formed. Iodine in aromatic compounds also shows the power to unite with chlorine. When chlorine is passed into a solution of iodobenzene in chloroform, a yellow crystalline precipitate of phenyliodoso chloride, $C_6H_5ICl_2$, is formed. When this compound is treated with potassium hydroxide it is converted into iodosobenzene, C_6H_5IO, which, on boiling with water, undergoes decomposition according to the following equation: —

$$2C_6H_5IO = C_6H_5I + C_6H_5IO_2$$

Phenyl iodide and iodoxybenzene are formed. The latter, as well as iodosobenzene, is an explosive compound.

When a mixture of iodosobenzene and iodoxybenzene is shaken with water and silver oxide, a substance is formed which has strongly basic properties. The reaction takes place according to the equation, —

$$C_6H_5IO + C_6H_5IO_2 + AgOH = (C_6H_5)_2I.OH + AgIO_3$$

The compound is called diphenyliodonium hydroxide — a name which indicates its relation to ammonium, sulphonium, and phosphonium compounds. Diphenyliodonium hydroxide, like other strong bases, forms well characterized salts with acids, which resemble in solubility the analogous salts of thallium. The compound is of special interest as in it iodine, which under other circumstances is an acid-forming element, plays the part of a base-forming element.

406. Chlortoluenes, $CH_3.C_6H_4Cl$. — *p*-Chlortoluene and *o*-chlortoluene are formed from toluene by the action of chlorine in the presence of a carrier. The ortho compound boils at 154° and the para compound at 160°. As the difference between the boiling-points of the two compounds is so small, it is impossible to separate them by fractional distillation. As a consequence, they are made from the corresponding nitrotoluenes by reactions similar to those indicated in the case of *m*-dibrombenzene.

407. Benzyl Chloride, $C_6H_5.CH_2Cl$, is formed when chlorine is passed into boiling toluene or into the cold hydrocarbon exposed to direct sunlight. It is a liquid which possesses a pungent odor, and boils at 178°. The compound enters into the reactions which are characteristic of aliphatic halogen derivatives. When boiled with dilute nitric acid it is oxidized to benzoic acid. By the further action of chlorine toluene is converted into *benzal chloride*, $C_6H_5.CHCl_2$ (b.p. 206°), and *benzotrichloride*, $C_6H_5.CCl_3$ (b.p. 213°). Benzal chloride is prepared commercially in the manufacture of benzaldehyde, $C_6H_5.CHO$, and benzotrichloride in the manufacture of benzoic acid, $C_6H_5.COOH$.

408. Benzophenone Chloride, $(C_6H_5)_2CCl_2$, is so called because it can be formed by the replacement of the oxygen atom in benzophenone, $(C_6H_5)_2CO$, by chlorine. This is effected by heating the ketone with phosphorus pentachloride: —

$$(C_6H_5)_2CO + PCl_5 = (C_6H_5)_2CCl_2 + POCl_3$$

The compound can be prepared by other methods, two of which illustrate general reactions. When chlorine is passed into diphenylmethane, which is gently heated, the hydrogen atoms joined to the methane carbon atom are replaced, one after the other, by the halogen. In this way diphenylchlormethane, $(C_6H_5)_2CHCl$, and diphenyldichlormerhane, $(C_6H_5)_2CCl_2$, may be prepared conveniently.. The latter compound may also be prepared by the Friedel and Crafts reaction from benzene and carbon tetrachloride, in the presence of aluminium chloride. If the reaction takes place in the cold and an excess of carbon tetrachloride is used, but two halogen atoms of the latter are replaced by phenyl. In the presence of an excess of benzene, triphenylchlormethane, $(C_6H_5)_3CCl$, is formed almost exclusively. Halogen derivatives of benzophenone chloride are readily prepared by condensing halogen derivatives of benzene with carbon tetrachloride. When chlorbenzene is used, a mixture of *p,p′*-dichlorbenzophenone chloride and *o,p′*-dichlorbenzophenone chloride is obtained.

The reactions of benzophenone chloride are those which are characteristic of ketone chlorides. The presence of the phenyl groups brings about a reactivity which is greater than that shown by the analogous derivatives of aliphatic ketones. Benzophenone chloride reacts rapidly at room-temperature with zinc; the halogen atoms are removed and tetraphenylethylene is formed: —

$$2(C_6H_5)_2CCl_2 + 2Zn = (C_6H_5)_2C:C(C_6H_5)_2 + 2ZnCl_2.$$

When treated with mercury, which is a less active metal, but one halogen atom enters into reaction, and tetraphenylethylene dichloride is formed: —

$$2(C_6H_5)_2CCl_2 + 2Hg = (C_6H_5)_2CCl-CCl(C_6H_5)_2 + 2HgCl.$$

When heated with water, benzophenone chloride is converted into benzophenone. The ketone chloride reacts with concentrated sulphuric acid in the cold and hydrochloric acid is formed. Benzophenone is precipitated when the solution is poured into water. Benzophenone chloride forms addition-products, which resemble to some extent double salts, with aluminium chloride, zinc chloride, and other chlorides. These compounds are decomposed by water into their constituents.

409. Triphenylchlormethane, $(C_6H_5)_3CCl$, which is also called triphenylmethyl chloride, is a compound which has attracted much attention lately on account of the fact that it yields a remarkable hydrocarbon, triphenylmethyl (**362**), when treated with zinc. The substance itself possesses unusual properties. It is best prepared by treating benzene with carbon tetrachloride in the presence of aluminium chloride. The halogen atom in triphenylchlormethane is very reactive. It is replaced by hydroxyl when the latter is allowed to stand with water at room-temperature: —

$$(C_6H_5)_3C.Cl + HOH \rightleftharpoons (C_6H_5)_3C.OH + HCl$$

The reaction is a reversible one, the equilibrium attained being determined by the amount of water present. When triphenylcarbinol is treated with concentrated hydrochloric acid, triphenylchlormethane is formed, the reaction being the reverse of that just given. Triphenylchlormethane shows many of the properties of certain inorganic salts. It enters into reactions of double decomposition. The halogen which it contains is precipitated as silver chloride, when a solution of triphenylchlormethane is treated with silver nitrate. It reacts with concentrated sulphuric acid in a manner which is analogous to that in which sodium chloride reacts with the acid: —

$$(C_6H_5)_3CCl + H_2SO_4 = (C_6H_5)_3HSO_4 + HCl$$

Triphenylchlormethane forms double salts with certain inorganic halides. The compound with aluminium chloride which is an example, has the formula $(C_6H_5)_3CCl.AlCl_3$. A solution of triphenylchlormethane in liquid sulphur dioxide conducts an electric current; it appears, therefore, to be dissociated into ions in solution. Triphenylbrommethane is more highly ionized than the analogous chlorine compound. All these facts indicate that triphenylchlormethane resembles in many respects an inorganic salt, and that carbon may be considered a base-forming element. A number of compounds related to triphenylcarbinol and triphenylmethyl chloride have been investigated. In order to indicate their relation to bases and salts they have been called carbonium compounds.

PROBLEMS

1. Write equations for reactions by which the following may be prepared: (*a*) $C_6H_5.CHCl_2$, (*b*) $C_6H_5.CHCl.CH_2Cl$, (*c*) *p*-$C_6H_4.C_3H_7.Cl$, (*d*) $CH_3.CO.C_6H_3Cl_2$, (*e*) $CH_3.CCl_2.C_6H_5$.

2. By what chemical tests could you distinguish between (*a*) $C_6H_4Cl.C_2H_5$ and $C_6H_5.CHCl.CH_3$, (*b*) $(C_6H_5)_2CCl_2$ and $(ClC_6H_4)_2CCl_2$, (*c*) C_6H_5COCl and $C_6H_4Cl.CHO$?

3. From the following data identify the compound described: The compound, which boiled at 225°, was shown to belong to the aromatic series and to contain chlorine. When shaken with a solution of sodium hydroxide, sodium chloride and a sodium salt of an organic acid were found. The acid liberated by the action of hydrochloric acid on the solution of its salt contained chlorine and melted at 153°.

4. From the following data identify the compound described: The compound, which melted at 71°, was shown to be aromatic and to contain chlorine and nitrogen. On oxidation it was converted into an acid which contained nitrogen, but no chlorine, and melted at 238°.

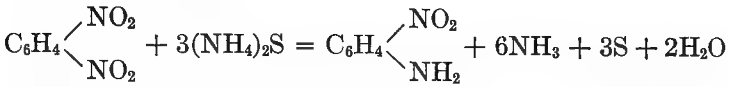
CHAPTER XXII

AROMATIC AMINES AND OTHER REDUCTION-PRODUCTS OF NITRO COMPOUNDS

410. A great variety of amines containing aromatic radicals is possible, and many are known. These may be divided into two classes: those in which the nitrogen atom present is in combination with a carbon atom in the ring, the so-called aryl amines, and those in which it is linked to a carbon atom in the side-chain. Benzylamine, $C_6H_5CH_2NH_2$, a member of the second class, may be considered as derived from methylamine by the replacement of one hydrogen atom of the methyl group by phenyl. It resembles methylamine closely in chemical properties, and can be prepared by a method analogous to that used in the case of the aliphatic amines, namely, the treatment of benzyl chloride with ammonia. While the aromatic amines which contain an amino group in direct combination with a carbon atom of the nucleus, show many of the properties of aliphatic amines, they are sharply differentiated from the latter in certain respects. It has been pointed out that compounds which contain atoms or groups in combination with aryl radicals do not possess all the chemical properties of analogous compounds in which these atoms or groups are linked to carbon atoms in an open chain. Chlorbenzene, for example, is much less reactive than ethyl chloride. For this reason aromatic amines cannot be prepared, in general, by the action of ammonia on aryl halides. They are commonly prepared by reducing nitro compounds: —

$$C_6H_5NO_2 + 6H = C_6H_5NH_2 + 2H_2O$$

The reduction is usually effected in the laboratory by means of tin and hydrochloric acid. Stannous chloride and hydrochloric acid, zinc or iron and acetic acid, and an alcoholic solution of ammonium sulphide are also used. Ammonium sulphide is of particular value when it is desired to reduce but one nitro group in a compound which contains two or more of these groups. For example, when *m*-dinitrobenzene is warmed with this reagent *m*-nitraniline is formed: —



$$C_6H_4\langle{}^{NO_2}_{NO_2} + 3(NH_4)_2S = C_6H_4\langle{}^{NO_2}_{NH_2} + 6NH_3 + 3S + 2H_2O$$

Certain amines are most conveniently prepared by heating hydroxyl compounds at 300° with the compound of zinc choride and ammonia. The naphthylamines, $C_{10}H_7NH_2$, are prepared in this way industrially from the naphthols, $C_{10}H_7OH$: —

$$2C_{10}H_7OH + ZnCl_2.2NH_3 = 2C_{10}H_7NH_2 + ZnCl_2.2H_2O$$

411. Primary Amines. — The primary aromatic monamines are liquids or solids which crystallize well. They are colorless when pure, but slowly turn brown when exposed to the air. They possess a characteristic odor, and are very difficultly soluble in water.

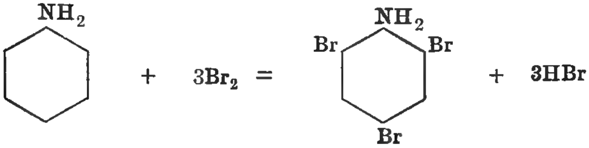
In many of their reactions the aromatic amines resemble the analogous aliphatic compounds. Owing to the presence of the negative phenyl group the aqueous solutions of the aryl amines are much less basic than those of the alkyl amines; an aqueous solution of aniline, $C_6H_5NH_2$, does not affect the color of red litmus. Notwithstanding this, the primary aryl amines form with strong acids well characterized salts, which crystallize from water. The salts are hydrolyzed by water, show an acid reaction, and are decomposed by soluble carbonates. The addition-products of the amines with the halogen hydrides form beautifully crystalline double salts some of which are difficultly soluble in water. A double salt of aniline hydrochloride and platinic chloride has the composition expressed by the formula $PtCl_4.2C_6H_5NH_3Cl$.

The primary amines unite with alkyl halides to form salts of secondary and tertiary amines and of the quarternary ammonium bases, the reactions being analogous to those already described in connection with the aliphatic amines. Like the latter they are converted into isocyanides when warmed with potassium hydroxide and an alcoholic solution of chloroform.

The aromatic amines react also with acyl chlorides and acid anhydrides. Aniline and acetyl chloride give, for example, acetanilide: —

$$CH_3COCl + H_2NC_6H_5 = CH_3CO.NHC_6H_5 + HCl$$

Amines react very readily with the free halogens, the introduction of the halogen atom into the ring being greatly facilitated by the presence of the amino group. When an aqueous solution of aniline is treated with bromine-water, symmetrical tribromaniline is precipitated: —



Nitrous acid serves to differentiate sharply primary alkyl amines from primary aryl amines. The salts of the former are converted into alcohols by this reagent. The reaction in the case of methylamine is expressed by the equation, —

$$CH_3NH_2.HCl + HNO_2 = CH_3OH + N_2 + H_2O + HCl$$

When a solution of a salt of an aryl amine, aniline, for example, is treated with nitrous acid, nitrogen is not evolved if the reaction takes place at room-temperature. A substance containing nitrogen, which is called a diazonium compound, is formed. The reaction in the case of aniline hydrochloride is expressed by the equation, —

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5N_2Cl + 2H_2O$$

The three hydrogen atoms in combination with the nitrogen atom are replaced by a nitrogen atom from the nitrous acid. The diazonium salts, which will be described in detail later, can be isolated. If the reaction between the amine and nitrous acid is brought about in hot water, or the solution of the diazonium salt prepared in the cold is heated, nitrogen is evolved, and a phenol, C_6H_5OH, is formed. It is, thus, seen that nitrous acid serves to replace an amino group in both alkyl amines and aryl amines by the hydroxyl group. The difference between the two classes consists in the fact that in the case of the aryl amines an intermediate product, the diazonium salt, can be isolated. It will be shown later that diazonium salts can be converted into a great variety of compounds — a fact which leads to the use of primary aryl amines in the preparation of many classes of compounds. Benzylamine, $C_6H_5CH_2NH_2$, like the simple alkyl amines, can not be converted into a diazonium compound.

412. Secondary Amines. — The aromatic secondary amines resemble closely the analogous aliphatic compounds. The differences which exist between the two classes can be traced to the fact that aryl groups are negative whereas alkyl groups are positive. Diphenylamine, $(C_6H_5)_2NH$, forms salts with strong solutions of active acids only, and when the salts are treated with water they are completely decomposed into the free amine and free acid. Methylaniline, $C_6H_5(CH_3)NH$, on the other hand, is, as might be expected, more strongly basic than aniline.

Secondary amines like methylaniline can be prepared by the direct addition of an aromatic amine and an alkyl halide: —

$$C_6H_5NH_2 + CH_3I = C_6H_5(CH_3)NH.HCl$$

As in the case of the aliphatic amines, the reaction does not stop with the formation of the salt of a secondary amine, but tertiary amines and quarternary ammonium bases are also formed.

Amines which contain two aryl radicals are prepared by reactions similar to those indicated by the following equations: —

$$C_6H_5NH_2 + C_6H_5NH_2.HCl = (C_6H_5)_2NH.HCl + NH_3$$
$$C_6H_5OH + C_6H_5NH_2 + ZnCl_2 = (C_6H_5)_2NH + ZnCl_2.H_2O$$

Like aliphatic amines, methylaniline and analogous compounds form salts with acids, and addition-products with alkyl halides. They are converted into nitroso compounds by nitrous acid, and into acyl derivatives when treated with acid anhydrides or acyl halides.

413. Tertiary Amines. — Amines of this class which contain both alkyl and aryl radicals are formed by the action of alkyl halides on primary or secondary aromatic amines. They are usually prepared commercially, however, by heating to a high temperature an aryl amine with an alcohol and hydrochloric acid: —

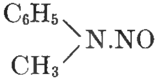
$$C_6H_5NH_2 + 2CH_3OH + HCl = C_6H_5N(CH_3)_2.HCl + 2H_2O$$

Amines which contain three aryl radicals can not be prepared by these methods. Triphenylamine is formed by heating brombenzene with a potassium derivative of aniline: —

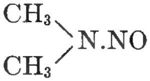
$$2C_6H_5Br + C_6H_5NK_2 = (C_6H_5)_3N + 2KBr$$

Compounds of this type do not form salts with acids.

Tertiary amines which contain both alkyl and aryl radicals resemble, in general, the aliphatic tertiary amines in their chemical behavior. The two classes are sharply differentiated, however, by their behavior with nitrous acid. While the aliphatic amines are either unaffected or oxidized by this reagent, the aromatic amines are converted into nitroso compounds. The nitroso derivatives of a secondary aromatic amine has a structure analogous to that of the nitroso derivatives of aliphatic amines. The constitution of nitroso-methylaniline and that of nitroso-dimethylamine are expressed, respectively, by the following formulas: —



$$\begin{matrix} C_6H_5 \searrow \\ \quad N.NO \\ CH_3 \nearrow \end{matrix}$$



$$\begin{matrix} CH_3 \searrow \\ \quad N.NO \\ CH_3 \nearrow \end{matrix}$$

In the nitroso derivatives of the tertiary amines, the characteristic group is linked to a carbon atom in the nucleus. The compound formed by the action of nitrous acid on dimethylaniline, for example, has the structure indicated by the formula, $NO.C_6H_4.N(CH_3)_2$.

414. Diamines. — Derivatives of aromatic hydrocarbons which contain two or more amino groups are known. They are prepared by reducing nitro compounds which contain two or more nitro groups. The diamines are colorless compounds which rapidly turn brown in the air, and are oxidized readily. When they are treated with an aqueous solution of ferric chloride characteristic colors are formed.

415. Aniline, $C_6H_5NH_2$, derives its name from the fact that it was first formed as the result of the distillation of indigo, for which the Spanish name is *anil*. It occurs in small quantities in coal-tar and in bone-oil. It is prepared in the laboratory by the reduction of nitrobenzene with tin and hydrochloric acid: —

$$C_6H_5NO_2 + 3Sn + 7HCl = C_6H_5NH_2.HCl + 3SnCl_2 + 2H_2O$$

Some stannic chloride is also formed, as stannous chloride in the presence of hydrochloric acid reduces nitrobenzene to aniline, and, as a result, is oxidized to stannic chloride: —

$$C_6H_5NO_2 + 3SnCl_2 + 7HCl = C_6H_5NH_2.HCl + 3SnCl_4 + 2H_2O$$

The product of the reaction is a mixture of the double-salts of aniline hydrochloride with stannous chloride and stannic chloride. If the product is allowed to cool when reaction is complete, the double-salts are obtained in crystalline condition. Aniline forms many double-salts with the halides of the less active metals. The tin salts have the composition expressed by the formulas

$$SnCl_4.2(C_6H_5NH_2.HCl) \text{ and } SnCl_2.C_6H_5NH_2.HCl$$

In order to liberate the aniline formed as the result of the reduction of nitrobenzene, the product of the reaction is treated with an excess of sodium hydroxide, and distilled with steam. Enough of the alkali must be added to precipitate the tin and to set free the aniline from its hydrochloride.

In the manufacture of aniline on the industrial scale, the reduction of nitrobenzene is effected by means of iron-filings and hydrochloric acid, and the amine is set free from its salt by lime.

Aniline is a colorless oily liquid, which turns brown on standing. It melts at $-8°$, boils at 183.7°, and has the specific gravity 1.024 at 16°. It is soluble in about 30 parts of water. An aqueous solution of free aniline gives a violet coloration with a solution of bleaching-powder, and a blue coloration with a solution of potassium dichromate. A solution of aniline which contains an acid, is colored dark green by potassium dichromate.

Aniline is converted into a sulphonic acid when heated with concentrated sulphuric acid, into halogen substitution-products by the halogens, and into nitro derivatives by nitric acid. These compounds will be considered in some detail later.

416. Acetanilide, $C_6H_5NH.COCH_3$, which is an important derivative of aniline, is an example of the compounds formed as the result of the replacement of a hydrogen atom in an aromatic amine by acyl radicals. Acetanilide is formed when aniline is treated with acetyl chloride or acetic anhydride: —

$$C_6H_5NH_2 + CH_3COCl = C_6H_5NH.COCH_3 + HCl$$

It is usually prepared by boiling for some hours aniline acetate, which is formed by mixing aniline and acetic acid: —

$$C_6H_5NH_2.CH_3COOH = C_6H_5NH.COCH_3 + H_2O$$

Acetanilide crystallizes from hot water in white prisms. It melts at 116° and boils at 304°. It is used in medicine in cases of fever, and in "headache powders."

Acetanilide is hydrolyzed when heated with an aqueous solution of a base: —

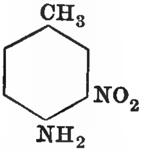
$$C_6H_5NH.COCH_3 + KOH = C_6H_5NH_2 + CH_3.COOK$$

The acetyl derivatives of aromatic amines are often used in the preparation of substitution-products of the amines. Aniline and its homologues are very reactive substances and, as a consequence, the reactions which they undergo with other compounds can not always be controlled. Aniline, for example, is largely converted into tribromaniline by bromine-water. It is not possible to prepare conveniently monobromaniline from the free amine. In order to decrease the activity of the compound, one of its hydrogen atoms is replaced by an acetyl radical. Acetanilide and bromine yield bromacetanilide, from which bromaniline is obtained by hydrolysis: —

$$C_6H_5NH.COCH_3 + Br_2 = BrC_6H_4NH.COCH_3 + HBr,$$
$$BrC_6H_4NH.COCH_3 + KOH = BrC_6H_4NH_2 + CH_3COOK.$$

Acetyl compounds are often used in the preparation of nitro derivatives of amines, and when it is desired to oxidize a side-chain in an amine.

417. Toluidines, $CH_3.C_6H_4.NH_2$. — The three isomeric toluidines are obtained by the reduction of the three nitrotoluenes. When toluene is nitrated the product of the reaction consists almost entirely of the para and ortho derivatives. From these *p*-toluidine (m.p. 45°, b.p. 198°) and *o*-toluidine (b.p.199°) are readily obtained. As the nitro group does not, under ordinary conditions, enter the ring in a position meta to a methyl radical, it is necessary to prepare *m*-nitrotoluene by an indirect method. This method is of interest, as it is a good example of the procedure adopted by chemists to introduce a substituent into a position which it will not enter normally. When *p*-toluidine is treated with nitric acid, there are two groups present, methyl and amino, which have a directing influence on the nitro group introduced into the compound. Both of these groups tend to send a substituent to the ortho and para positions. As in *p*-toluidine the position para to methyl is occupied by the amino group, the entering group must take its place ortho to either methyl or amino. The latter being more basic than methyl exerts a stronger directing influence, and, as a consequence, the chief product of the reaction has the structure represented by the formula, —



The yield of nitro compound is small when *p*-toluidine is nitrated, as amines, in general, undergo deep seated changes when treated with nitric acid. In order to prevent this the acetyl derivative of *p*-toluidine is nitrated, and the free amine obtained from the resulting product by saponification.

In this way a nitro group is introduced into the ring in a position meta to the methyl radical. In order to obtain nitrotoluene from the nitrotoluidine formed in this way, the amino group present in the latter must be removed. This is accomplished by converting the amine into a diazo compound (**429**), and boiling the latter with alcohol, when the diazo group is replaced by hydrogen: —

$$CH_3.C_6H_3(NO_2)N_2Cl + C_2H_5OH = CH_3.C_6H_4.NO_2 + N_2 + HCl + CH_3.CHO$$

m-Toluidine is obtained by reducing *m*-nitrotoluene formed by this roundabout process.

As the boiling-points of *o*-, *m*-, and *p*-toluidine are, respectively, 199°, 200°, and 198°, it is impossible to identify these compounds by a determination of their boiling-points. The identification can be effected, however, by a determination of the melting-points of their acetyl derivatives, which are formed when the amines are treated with acetic anhydride. The acetyl derivatives of *o*-, *m*-, and *p*-toluidine melt at 107°, 65°, and 147°, respectively. In order to identify a substance it is necessary to determine the physical properties of the substance and of at least one of its derivatives. The method used in the identification of the toluidines is an excellent example of this principle.

418. Benzylamine, $C_6H_5CH_2NH_2$, is an example of an amine with the amino group in the side-chain. It can be obtained by the methods used to prepare methylamine. As in the case of the purely aliphatic amine, secondary and tertiary amines are formed. In order to prevent this, benzyl chloride may be treated with acetamide instead of with ammonia: —

$$C_6H_5CH_2Cl + NH_2.COCH_3 = C_6H_5CH_2NH.COCH_3 + HCl$$

From the acetyl derivative of benzylamine formed in this way, the free amine is obtained by hydrolysis.

Benzylamine is a liquid of ammoniacal odor, which boils at 185°, has the specific gravity 0.983 at 19°, and absorbs carbon dioxide from the air. It shows the properties characteristic of aliphatic amines, and cannot be converted into a diazo compound.

419. Naphthylamines, $C_{10}H_7NH_2$. — *α*-Naphthylamine is most conveniently prepared by heating *α*-naphthol, $C_{10}H_7OH$, with the ammonia compound of calcium chloride or zinc chloride: —

$$C_{10}H_7.OH + NH_3 = C_{10}H_7.NH_2 + H_2O$$

It possesses a disagreeable fæcal-like odor, sublimes readily, and turns brown in the air. It crystallizes in colorless needles or prisms, melts at 50°, and boils at 300°. Solutions of its salts give a blue precipitate with ferric chloride and other oxidizing agents.

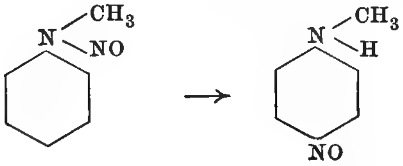
β-Naphthylamine is prepared from *β*-naphthol, by the method employed in the case of its isomer. It crystallizes in glancing mother-of-pearl plates, melts at 112°, boils at 294°, and has no odor. It is not colored by oxidizing agents.

The naphthylamines are used extensively in the manufacture of dyes.

420. Methylaniline, $C_6H_5.NHCH_3$, is an example of a secondary amine which contains an aryl and an alkyl radical. It is prepared commercially for use in the manufacture of dyes by heating aniline hydrochloride with methyl alcohol. Methylaniline is an oil, lighter than water, which boils at 192°.

When a solution of methylaniline in an acid is treated with nitrous acid, *nitrosomethylaniline,* $C_6H_5.N(NO)CH_3$, is formed. The compound is a yellow oil of aromatic odor, which cannot be distilled without decomposition. It can be distilled with steam unchanged, however. On careful reduction it is converted into a derivative of hydrazine, $C_6H_5N(CH_3).NH_2$, and when treated with tin and hydrochloric acid, the nitroso group is eliminated and methylaniline is formed.

Nitrosomethylaniline and similar compounds undergo a molecular rearrangement when heated with a solution of hydrogen chloride in alcohol; the nitroso group enters into combination with the carbon atom para to the nitrogen atom. In this way nitrosomethylaniline, which is also called methylaniline-nitrosamine, is converted into *p*-nitrosomethylaniline: —



The last-named compound unites with acids to form salts, whereas the compound which contains the nitroso group in combination with nitrogen lacks basic properties.

421. Diphenylamine, $(C_6H_5)_2NH$, is an example of a purely aromatic amine. The method used in its preparation has been discussed under secondary amines (**412**). Diphenylamine has an agreeable odor, melts at 54°, and boils at 310°. It serves as a reagent for the detection of traces of nitric acid and other oxidizing substances. When a solution of the amine in concentrated sulphuric acid is treated with a trace of nitric acid, a deep blue color is developed.

422. Dimethylaniline, $C_6H_5.N(CH_3)_2$, is an oil, which solidifies when cooled by a freezing-mixture, and boils at 192°. The hydrogen atom of the amine which is in the position para to the $N(CH_3)_2$ group is very reactive. As a consequence, dimethylaniline forms condensation-products when treated with a variety of compounds. For example, when the amine and benzoic aldehyde, $C_6H_5.CHO$, are heated in the presence of zinc chloride, condensation takes place: —

$$C_6H_5.CHO + 2C_6H_5N(CH_3)_2 = C_6H_5.CH[C_6H_4N(CH_3)_2]_2 + H_2O$$

Reactions of this type will be discussed later in the consideration of dyes.

When a solution of dimethylaniline in an acid is treated with nitrous acid, a salt of *p-nitrosodimethylaniline* is formed: —

$$C_6H_5.N(CH_3)_2.HCl + HNO_2 = NO.C_6H_4.N(CH_3)_2.HC + H_2O.$$

The salt so formed crystallizes in yellow needles. The free amine, which is liberated from its salts by bases, crystallizes in green plates, which melt at 85°. When *p*-nitrosodimethylaniline is boiled with an alkali, dimethylamine and a salt of nitrosophenol are formed: —

$$NO.C_6H_4.N(CH_3)_2 + KOH = NO.C_6H_4.OK + (CH_3)_2NH$$

The reaction furnishes the most convenient way of preparing dimethylamine.

423. Identification of Aromatic Amines. — Most aromatic amines are soluble in hydrochloric acid, and are precipitated from the solution of their salts so formed by bases. Aqueous solutions of the amines, even when very dilute, yield precipitates of bromine substitution-products when treated with bromine water. The reaction is not characteristic, however, as phenols act in a similar way.

The class to which an amine belongs can be determined by treating it with acetyl chloride or acetic anhydride. The reactions which take place with these substances are analogous to those described under the aliphatic amines. Benzenesulphonyl chloride is of particular value in distinguishing primary, secondary, and tertiary amines from one another. The reactions have already been described (**395**).

The behavior of aromatic amines with nitrous acid is characteristic. The reagent serves to distinguish not only primary, secondary, and tertiary amines from one another, but aromatic amines from aliphatic amines in the case of primary and tertiary compounds.

When a compound has been shown to be an amine, and the class to which it belongs has been ascertained, its identification is completed by the determination of the melting-point or boiling-point of a compound prepared from it. Acetyl derivatives are frequently prepared in identifying amines, as many of them melt sharply and crystallize well from water.

INTERMEDIATE REDUCTION-PRODUCTS OF NITROBENZENE

424. The substance formed when nitrobenzene is reduced is determined by the nature of the reducing agent used. When, for example, hydrogen generated by the action of a metal on an acid is the reducing agent, aniline is formed; when the reduction is effected by treating nitrobenzene with zinc dust and water, the reaction-product is phenylhydroxylamine, $C_6H_5.NHOH$.

The study of the reduction of organic compounds has led to the important conclusion that the various reducing agents differ markedly in the effect they produce. When a compound is reduced by "nascent" hydrogen, the composition of the resulting product is determined by the manner in which the hydrogen is formed. When, for example, acetone, $(CH_3)_2CO$, is reduced by hydrogen generated by the action of sodium on water, the chief product of the reaction is isopropyl alcohol, $(CH_3)_2CHOH$, whereas when the hydrogen is liberated from an acid by zinc, reduction takes place to a slight degree only, and propane $(CH_3)_2CH_2$, is formed. The activity of a reducing agent is determined by the energy relations involved in the changes which take place during reduction. When "nascent" hydrogen is the reducing agent, its activity is determined by what may be called the pressure or tension under which it is liberated. This pressure can be varied by selecting various combinations of substances which yield hydrogen, or by generating the gas by means of electricity. When an electric current is passed through a solution of an acid or base hydrogen is set free. The tension under which the gas is evolved is determined by the conditions under which the experiment is carried out. These conditions may be varied, and, as a consequence, the " strength " as a reducing agent of the liberated hydrogen may be varied.

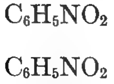
An examination of the methods used to prepare the various reduction-products of nitrobenzene brings out clearly the fact that reducing agents differ among themselves in activity. The study of the action of oxidizing agents on organic compounds has led to a similar conclusion in the case of these substances.

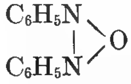
The primary reduction-products of nitrobenzene are represented by the following formulas: —

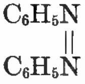
$$C_6H_5NO_2 \rightleftarrows C_6H_5NO \underset{O}{\overset{H}{\rightleftarrows}} C_6H_5NHOH \rightleftarrows C_6H_5NH_2$$

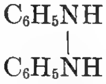
By reduction, it is possible to pass from nitrobenzene to aniline through the intermediate compounds nitrosobenzene and phenylhydroxylamine, and by oxidation in the reverse direction. It has been shown that nitrosobenzene and phenylhydroxylamine are formed in the electro-reduction of nitrobenzene, but it is impossible, at present, to effect some of the transformations indicated above in such a way that the reactions can be used as preparative methods. Some, however, can be used for this purpose. Phenylhydroxylamine, for example, is oxidized in the cold by potassium bichromate and sulphuric acid to nitrosobenzene, and is converted by reducing agents into aniline. In certain cases it is possible, by selecting the proper reagent, to effect the change indicated by two of the steps noted above. Phenylhydroxylamine is best prepared by treating with zinc dust a solution of nitrobenzene in dilute alcohol which contains a small amount of calcium chloride.

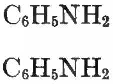
The effect of reducing agents on nitrobenzene is clearly shown by a study of the series of what may be called secondary reduction-products, which contain two benzene rings; the composition of these compounds is represented by the following formulas:

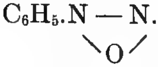

Nitrobenzene


Azoxybenzene


Azobenzene


Hydrazobenzene


Aniline

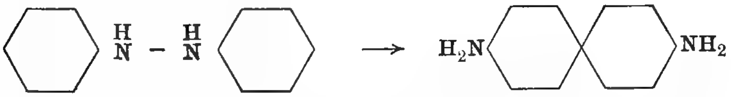


425. Azoxybenzene, $C_6H_5.N\overset{}{\underset{\diagdown O \diagup}{—}}N.C_6H_5$, is obtained by boiling nitrobenzene with an alcoholic solution of potassium hydroxide. Alcohol in the presence of an alkali is frequently used as a mild reducing agent. Azoxybenzene is formed when an alcoholic solution of aniline is treated with potassium permanganate. It is a light yellow, crystalline substance, which melts at 36°. Active reducing agents convert it into aniline.

426. Azobenzene, $C_6H_5.N=N.C_6H_5$, is prepared by reducing nitrobenzene with a solution of sodium stannite, which is made by treating stannous chloride with an excess of sodium hydroxide. It will be recalled that stannous chloride in acid solution reduces nitrobenzene to aniline. The difference between the activity of a reducing-agent in an acid solution and the activity of the same reagent in alkaline solution, which is seen here, has been noted in other cases. Azobenzene is formed when azoxybenzene is distilled with iron-filings. It forms orange-red crystals, melts at 68°, boils at 295°, and is converted into aniline by active reducing agents.

427. Hydrazobenzene, $C_6H_5NH.NHC_6H_5$, is formed by the reduction of nitrobenzene by zinc-dust in alkaline solution. The presence of the alkali is necessary, as in neutral solution phenylhydroxylamine is formed, and in acid solution aniline is the reduction-product. Hydrazobenzene forms colorless crystals which melt at 126°. It is readily oxidized to azobenzene, the change being effected by ferric chloride, and slowly by the oxygen of the air.

Under the influence of strong acids hydrazobenzene undergoes a molecular rearrangement, as the result of which *benzidine,* which is diaminodiphenyl, is formed: —



Benzidine is formed directly by reducing azobenzene in acid solution. The structure of the amine has been shown to be that indicated, by converting it into diphenyl. The amino groups may be replaced by hydrogen by the method outlined in the case of nitrotoluidine (**417**). Benzidine crystallizes in colorless, silky plates, which melt at 122°. It is characterized by its solubility in hot water, and the sparing solubility of its sulphate. It is used in large quantities in the manufacture of certain dyes.

PROBLEMS

1. Write equations for reactions by which (*a*) $C_6H_5NHC_2H_5$ may be prepared from $C_6H_5NH_2$, (*b*) *p*-$C_6H_4.C_3H_7.NHC_2H_5$ from C_6H_6, (*c*) $C_6H_3.CH_3.Br.NH_2$ (1, 2, 4) from $C_6H_5.CH_3$, (*d*) *m*-$C_6H_4.NH_2.SO_3H$ from C_6H_6.

2. By what chemical reactions could the following be distinguished from each other: (*a*) $C_6H_4CH_3.NH_2$ and $C_6H_5CH_2NH_2$, (*b*) $C_6H_5N(CH)_3)_2$ and $(C_6H_5)_3N$, (*c*) $C_6H_5CONH_2$ and $C_6H_4.CH_3.NH_2$, (*d*) $C_6H_5CO.NHCH_3$ and $CH_3CO.NHC_6H_5$, (*e*) $C_6H_4.Cl.NH_2$ and $C_6H_5.NH_2.HCl$, (*f*) $C_6H_4.NH_2.COOH$ and $C_6H_4.NO_2.COOH$, (*g*) $NH_4.C_6H_4.SO_3H$ and $C_6H_5NH_2.H_2SO_4$.

3. Identify the compound which was studied with the following results: The compound, which melted at 45° and contained nitrogen, was insoluble in water and sodium hydroxide, was soluble in dilute hydrochloric acid, and was converted when heated with concentrated sulphuric acid into a compound soluble in alkalies. It reacted with acetyl chloride and formed a compound which melted at 147.

CHAPTER XXIII

DIAZO COMPOUNDS

428. The compounds formed by the action of nitrous acid on the salts of primary aromatic amines are of great theoretical interest and practical importance. The compound obtained from aniline hydrochloride has the composition represented by the formula $C_6H_5N_2Cl$. As it contains two nitrogen atoms, it was originally called a diazo compound, the second syllable of the name being derived from *azote*, the French word for nitrogen. Since their discovery in 1860 by Griess the diazo compounds have been much studied. They are very reactive and yield various classes of compounds, among which are important dyes, when they enter into reaction with other substances.

Diazo compounds are formed when an acidified aqueous solution of a salt of a primary aromatic amine is treated with a solution of sodium nitrite. The reaction which takes place in the case of aniline hydrochloride is represented by the equation,—

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5N_2Cl + 2H_2O$$

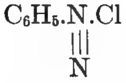
The diazo compound prepared in this way from aniline hydrochloride can not be isolated, as it is soluble in water and decomposes when an attempt is made to obtain it by evaporation of the solution. In the use of diazo compounds to prepare other substances it is, in general, unnecessary to isolate them and the reactions are, accordingly, carried out in aqueous solution. When it is desired to obtain the diazo compounds in pure condition, they are prepared in a different way. In this method the salt of the amine is suspended in alcohol and treated either with amyl nitrite or with the oxides of nitrogen formed by heating arsenous acid with nitric acid. When reaction is complete, ether is added to precipitate the salt of the diazo compound, which is obtained in crystalline condition.

The salts of the diazo compounds are soluble in water, and resemble inorganic salts in certain respects. Their solutions conduct an electric current, and enter into the ordinary reaction of double decomposition. The chlorides form double salts such as those with platinum, $PtCl_4.2C_6H_5N_2Cl$, and with gold, $AuCl_3.C_6H_5N_2Cl$. The determinations of the conductivity of the salts lead to the conclusion that they are ionized to about the same extent as ammonium salts. When a solution of the diazo compound prepared from aniline hydrochloride is treated with silver oxide, silver chloride is precipitated, and an alkaline solution is obtained: —

$$C_6H_5N_2Cl + AgOH = C_6H_5N_2OH + AgCl$$

The diazo compound formed in this way is a strong base.

All these facts lead to the conclusion that the diazo compounds contain a pentavalent nitrogen atom, as it is only when nitrogen possesses this valence that its compounds show the properties of bases and salts. In order to emphasize this conclusion and thus indicate the analogy between the diazo and ammonium compounds, the word diazo has been replaced by the word *diazonium* in naming the compounds which have been described above. The compound of the formula $C_6H_5N_2Cl$ is, thus, benzenediazonium chloride; its structure is represented by the formula, —



$$C_6H_5.\underset{\underset{\displaystyle N}{|||}}{N}.Cl$$

It will be shown later that compounds of the structure $C_6H_5.N{=}N.X$ exist; these are called diazo compounds, and do not possess the salt-like properties of the diazonium compounds.

429. Reactions of Diazonium Salts. — The diazonium salts enter into reaction with various classes of compounds, and, as a result, are much used in the synthesis of other substances. The reactions are of two types, — those in which the nitrogen is eliminated, and those in which it is not eliminated. The reactions of the first type result in the replacement of the diazonium group by other groups. The more important of these are as follows: —

1. *Replacement of the diazonium group by hydroxyl* can be effected by heating the diazonium salt with water: —

$$C_6H_5N_2Cl + HOH = C_6H_5OH + N_2 + HCl$$

In this way aniline, $C_6H_5NH_2$, can be converted into phenol, C_6H_5OH. As aromatic amines are prepared from nitro compounds, which are formed by the action of nitric acid on hydrocarbons, the reaction furnishes what is at times the most convenient method of introducing a hydroxyl group into a hydrocarbon.

2. *Replacement of the diazonium group by alkoxyl groups.* — Diazonium salts react with the organic substitution-products of water, such as alcohols and phenols: —

$$C_6H_5N_2Cl + HOCH_3 = C_6H_5OCH_3 + N_2 + HCl$$

When a diazonium salt is boiled with an alcohol, an ether which contains an aryl and an alkyl group is formed.

3. *Replacement of the diazonium group by hydrogen.* — In certain cases diazonium salts are converted into hydrocarbons when heated with alcohols: —

$$C_6H_5N_2Cl + C_2H_5OH = C_6H_6 + N_2 + CH_3CHO + HCl$$

The alcohol loses hydrogen, which takes the place of the diazonium group, and is thereby converted into an aldehyde. Whether hydrogen or an alkoxyl group enters into combination with the aryl radical is determined by the nature of the diazonium compound and alcohol, and by the conditions under which decomposition takes place, such as the temperature and the pressure.

4. *Replacement of the diazonium group by halogens.* — This reaction is accomplished by heating an aqueous solution of the diazonium salt with hydrochloric, hydrobromic, or hydriodic acid. The yield of the chloride and bromide formed is greatly increased by effecting the decomposition in the presence of finely-divided copper (Gattermann reaction), or by pouring the solution of the diazonium salt into a warm solution of cuprous chloride or cuprous bromide (Sandmeyer's reaction). Replacement of the diazonium group by iodine takes place readily when a solution of the diazonium salt which contains free acid is warmed with a solution of potassium iodide. In the preparation of bromides and iodides the sulphate of the amine is commonly used: —

$$C_6H_5N_2.SO_4H + HI = C_6H_5I + N_2 + H_2SO_4$$

As iodine substitution-products are not formed readily by the action of the free halogen on hydrocarbons, iodo-derivatives are usually prepared from amines by means of the diazo reaction.

5. *Replacement of the diazonium group by the CN group.* — This is readily effected by adding the solution of the diazonium salt to a warm solution of cuprous cyanide in potassium cyanide:

$$C_6H_5N_2Cl + KCN = C_6H_5CN + N_2 + KCl$$

The reaction is much used, as it furnishes a convenient method of preparing nitriles, which are converted by hydrolysis into acids.

6. *Replacement of the diazonium group by hydrocarbon residues.* — When dry diazonium salts are warmed with hydrocarbons in the presence of aluminium chloride, the N_2 group is replaced by aryl radicals: —

$$C_6H_5N_2Cl + C_6H_6 = C_6H_5.C_6H_5 + N_2 + HCl$$

When an aqueous solution of a diazonium salt is heated with an excess of a phenol, a derivative of diphenyl is obtained: —

$$C_6H_5N_2Cl + C_6H_5OH = C_6H_5.C_6H_4OH + N_2 + HCl$$

p-Hydroxydiphenyl is conveniently prepared in this way; a small amount of the ortho compound is formed at the same time.

7. *Replacement of the diazonium group by sulphur and nitro and other groups* has been effected in a number of cases, but the reactions have not been generally applied in synthetic work.

The reactions of the second type into which diazonium salts enter consist of condensations with other compounds as the result of which substances are formed which contain the diazo group, R–N=N–.

430. Diazoamino Compounds. — When a diazonium salt is treated with an aromatic primary or secondary amine in neutral solution, or in the presence of a weak acid like acetic acid, condensation takes place and a diazoamino compound is formed:

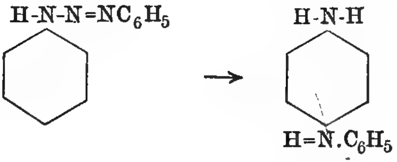
$$C_6H_5N_2\underline{Cl + H}NH.C_6H_5 = C_6H_5N_2.NH.C_6H_5 + HCl$$

Diazoaminobenzene crystallizes from benzene in flat yellow prisms, which melt at 96°.

The diazoamino compounds crystallize well and are comparatively stable. They are very weak bases, and form, in certain cases, double salts with hydrochlorplatinic acid. In acid solution they are converted by nitrous acid into diazonium salts: —

$$C_6H_5N_2NHC_6H_5 + HNO_2 + 2HCl = 2C_6H_5N_2Cl + 2H_2O$$

Diazoamino compounds undergo a rearrangement when warmed with an amine and a salt of an amine. When diazoaminobenzene, for example, is heated at 40° with aniline and aniline hydrochloride, *p*-aminoazobenzene is formed: —



In the rearrangement the diazo group exchanges places with the hydrogen atom para to the nitrogen atom joined to the ring. A similar rearrangement has been noted in the case of nitrosomethylaniline (**420**) and other derivatives of amines which contain a negative group in combination with nitrogen. It will be shown later that the diazonium group, $C_6H_5\underset{\underset{N}{|||}}{N}-$ is positive, while the isomeric diazo group $C_6H_5N=N-$, which is present in diazoaminobenzene, is negative.

431. Aminoazo Compounds are formed as the result of the rearrangement of diazoamino compounds, or by the condensation of diazonium salts with tertiary aromatic amines. Benzenediazonium chloride and dimethylaniline condense to form *p*-dimethylaminoazobenzene: —

$$C_6H_5N_2\underline{\vdots Cl + H\vdots}C_6H_4N(CH_3)_2 =$$
$$C_6H_5N:N.C_6H_4N(CH_3)_2 + HCl$$

They can also be prepared by the reduction of the compounds formed by the nitration of azo compounds: —

$$C_6H_5N:NC_6H_4NO_2 + 6H = C_6H_4N:NC_6H_4NH_2 + 2H_2O$$

The aminoazo compounds are weak bases. Those which contain the amino group are converted into diazo compounds by nitrous acid. Reducing agents convert them into amines. Thus, *p*-dimethylaminoazobenzene yields aniline and dimethyl-*p*-phenylene-diamine on reduction: —

$$C_6H_5N:NC_6H_4N(CH_3)_2 + 4H = C_6H_5NH_2 + H_2NC_6H_4N(CH_3)_2$$

p-Aminoazobenzene crystallizes in yellow leaflets, melts at 127°, and boils without decomposition at 360°. Its stability is noteworthy. It forms a hydrochloride which crystallizes in violet needles. It is converted by reducing agents into aniline and *p*-phenylene-diamine. Aminoazobenzene and its derivatives are used as dyes.

432. Hydroxyazo Compounds. — Diazonium salts react with phenols in the presence of alkalies to form hydroxyazo compounds: —

$$C_6H_5.N_2Cl + C_6H_5OH = C_6H_5.N:N.C_6H_4OH$$

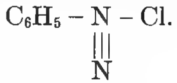
The azo group enters the position para to hydroxyl; and if this is occupied an ortho compound is formed. The directing influence of the hydroxyl group is, thus, the same as toward atoms or simple groups. *p*-Hydroxyazobenzene (also called oxyazobenzene) crystallizes in orange-colored prisms which melt at 150°. Hydroxyazo compounds are valuable dyes.

433. Hydrazines. — The diazonium salts are converted into amines by active reduction; if, however, the process is regulated, hydrazines are formed. When one mole of benzenediazonium chloride is treated with the amount of stannous chloride and hydrochloric acid equivalent in reducing power to four grams of hydrogen, phenylhydrazine hydrochloride is formed: —

$$C_6H_5N_2Cl + 4H = C_6H_5NH.NH_2.HCl$$

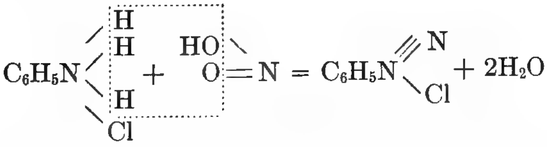
The hydrazines possess basic properties, and yield crystalline salts with acids. They are decomposed into amines and ammonia by energetic reducing agents, and are readily affected by oxidizing agents. Phenylhydrazine sulphate, for example, is converted into benzene diazonium sulphate by mercuric oxide, and into water, nitrogen, and benzene by an alkaline solution of a cupric salt. Phenylhydrazine is a colorless oily liquid, which turns brown in the air, solidifies at a low temperature, and boils with slight decomposition at 243.5°. It is sparingly soluble in water, and is an active poison. Phenylhydrazine has been of great value in the investigation of carbohydrates. It is a valuable reagent in the study of aldehydes and ketones.

434. Structure of Diazo Compounds. — The reasons for the view that the diazo compounds which are formed in acid solution contain a pentavalent nitrogen atom have been given (**428**). This view leads to the conclusion that benzenediazonium chloride has the structure represented by the formula



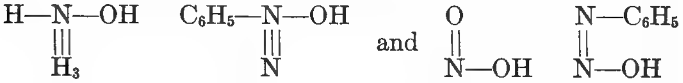
$$C_6H_5-\underset{\underset{N}{|||}}{N}-Cl.$$

Another arrangement of the molecule which contains pentavalent nitrogen, is possible, namely, $C_6H_5{-}N{\equiv}N.Cl$. This formula is rejected, however, because it does not represent the close analogy which exists between the diazonium salts and ammonium salts, because the reactions of the former with other substances can not be so readily interpreted through its aid, and because it contains two pentavalent nitrogen atoms. The nitrogen which is introduced into the salt of an amine when it is converted into a diazonium compound comes from nitrous acid, in which the nitrogen atom has the valence of three. Further, the formation of a diazonium salt from the salt of amine by the action of nitrous acid, is explicable, if we accept the view that the acid radical of the diazonium salt is linked to the nitrogen atom directly in combination with the aryl radical. The formation of the diazonium salt is represented by the following equation: —



According to this conception of the reaction, the diazonium salt is formed as the result of the replacement of the three hydrogen atoms in the salt of the amine by the trivalent nitrogen atom of nitrous acid.

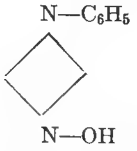
435. When a solution of benzenediazonium chloride is shaken with silver oxide, silver chloride is precipitated, and a strongly alkaline solution is formed. This solution reacts with potassium hydroxide, and a salt is formed called potassium benzenediazoate. The reaction has no analogy among inorganic compounds, as bases do not react with strong bases to form salts. For this reason it is assumed that benzenediazonium hydroxide, which is a strong base, undergoes molecular rearrangement in the presence of an alkali into an isomeric form, which possesses the properties of an acid. The diazonium hydroxide is a substitution-product of ammonium hydroxide, and the isomeric form is a substitution-product of nitrous acid. The relation between the two forms is shown by the following formulas, —



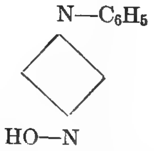
$$\begin{array}{ccccccc} \mathrm{H-N-OH} & \quad & \mathrm{C_6H_5-N-OH} & & \mathrm{O} & & \mathrm{N-C_6H_5} \\ ||| & & ||| & \text{and} & \| & & \| \\ \mathrm{H_3} & & \mathrm{N} & & \mathrm{N-OH} & & \mathrm{N-OH} \end{array}$$

This hypothesis is in accord with the fact that benzenediazonium hydroxide is a base and benzenediazo hydroxide is an acid.

The study of the salts of benzenediazo hydroxide has lead to the discovery of facts which make it necessary to broaden still further the hypothesis of the structure of diazo compounds. When potassium benzenediazoate is heated with a strong solution of potassium hydroxide, it is converted into an isomeric salt, which is very stable and forms derivatives which differ widely in properties from the analogous derivatives of its isomer. The explanation which has been put forward of the isomerism in this case is based on stereochemical considerations. The arrangement of the atoms in the case of benzenediazo hydroxide is illustrated by the following formulas: —



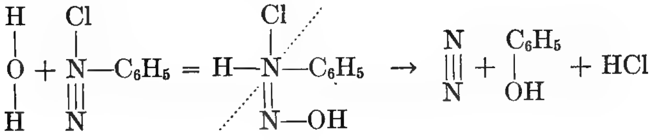
syn-diazohydroxide



anti-diazohydroxide

The cause of the isomerism is similar to that between fumaric acid and maleic acid (**112**). In the case of the nitrogen compounds the *syn*-form resembles the *cis*-form in the carbon compounds, and the *anti*-form, the *trans*-form. The *syn*-structure is assigned to the compounds which are unstable and readily enter into reactions with other substances. It is assumed that when the groups joined to nitrogen are situated on the same side of the molecule they can enter into reaction with each other more readily. A similar assumption was made in the case of the *cis*-forms of the stereoisomers which result from the presence of a double bond between carbon atoms.

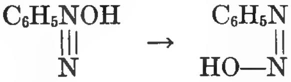
436. It remains to be shown how the hypotheses which have been outlined may be applied in interpreting the reactions of diazo compounds. The reactions which result in the elimination of nitrogen and the formation of substitution-products of the aromatic hydrocarbons, are explained as follows: The diazonium salts are first converted into *syn*-diazo compounds by the substances with which they undergo decomposition, and the diazo compound then loses nitrogen. This view is expressed by the following equation when applied to the case of benzenediazonium chloride and water: —



$$\begin{array}{c}\mathrm{H}\\|\\\mathrm{O}\\|\\\mathrm{H}\end{array} + \begin{array}{l}\mathrm{Cl}\\|\\\mathrm{N{-}C_6H_5}\\|||\\\mathrm{N}\end{array} = \begin{array}{l}\qquad\ \mathrm{Cl}\\\qquad\ \ |\\\mathrm{H{-}N{-}C_6H_5}\\\qquad\ \ \|\\\qquad\ \mathrm{N{-}OH}\end{array} \rightarrow \begin{array}{c}\mathrm{N}\\|||\\\mathrm{N}\end{array} + \begin{array}{c}\mathrm{C_6H_5}\\|\\\mathrm{OH}\end{array} + \mathrm{HCl}$$

Hantzsch, who put forward this hypothesis as to the way in which diazonium compounds undergo decomposition, has isolated in the case of certain diazonium derivatives the intermediate *syn*-diazo compounds. When *p*-chlorbenzenediazonium chloride, $ClC_6H_4N_2Cl$, is treated with a cyanide, *p*-chlorbenzonitrile, ClC_6H_4CN, is not immediately formed. The resulting product reacts energetically when treated with copper-powder and nitrogen and the nitrile are formed. This intermediate compound is considered to be the *syn*-diazo cyanide, as it does not possess the properties of diazonium salts. The *syn*-compound is unstable, and on standing is converted into an isomer, which does not react with copper-powder; this appears to be the *anti*-diazo compound.

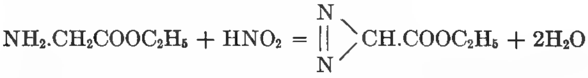
When diazonium salts react in the absence of free acid with amines and phenols, derivatives of azobenzene are formed. As these contain trivalent nitrogen atoms only, it is assumed that in neutral or alkaline solutions the diazonium hydroxides rearrange to diazo hydroxides,



$$\begin{matrix} C_6H_5NOH \\ ||| \\ N \end{matrix} \rightarrow \begin{matrix} C_6H_5N \\ || \\ HO{-}N \end{matrix}$$

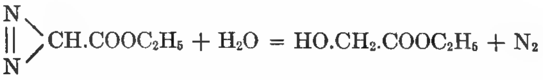
and that the latter undergo condensation with the amine or phenol.

437. Aliphatic Diazo Compounds. — It has been stated that primary aliphatic amines do not yield diazonium compounds when treated with nitrous acid. It is of interest to note, however, in connection with the aromatic diazo compounds, that certain derivatives of the aliphatic amines yield compounds when treated with nitrous acid which resemble somewhat in their reactions the diazonium compounds. When the ethyl ester of aminoacetic acid is treated with nitrous acid a yellow oil is obtained, which explodes when heated. The reaction takes place according to the equation,—



$$NH_2.CH_2COOC_2H_5 + HNO_2 = \begin{matrix} N \\ || \\ N \end{matrix}\!\!>CH.COOC_2H_5 + 2H_2O$$

Diazoacetic ester is converted by water into ethyl glycollate,



$$\begin{matrix} N \\ || \\ N \end{matrix}\!\!>CH.COOC_2H_5 + H_2O = HO.CH_2.COOC_2H_5 + N_2$$

into ethyl chloracetate by hydrochloric acid, and into ethyl diiodoacetate by iodine. It is of interest to note that while methylamine does not react with nitrous acid to form a compound which contains two nitrogen atoms, a derivative of the amine formed by replacing one hydrogen atom by the negative group $COOC_2H_5$, does form such a compound. It is possible that the difference in behavior toward nitrous acid of the aliphatic and aromatic amines, is due in part to the fact that the former contain positive radicals, whereas the latter contain weakly negative radicals.

Diazomethane, CH_2N_2, has been prepared by a series of reactions which cannot be discussed here. It is a yellow gas, which reacts with hydrochloric acid to form methyl chloride, and with organic acids to form methyl esters.

PROBLEM

1. Show by equations how the following substances may be prepared through the aid of the diazo reaction in connection with the synthetic methods which have been described: (*a*) *p*-$C_6H_4.CH_3.OH$ from $C_6H_5.CH_3$, (*b*) *m*-$C_6H_4.NO_2.I$ from C_6H_6, (*c*)*o*-$C_6H_4.CH_3.OCH_3$ from $C_6H_5.CH_3$, (*d*) 1, 3, 5-tribrombenzene from $C_6H_5.NH_2$, (*e*) *p*-$C_6H_4.CH_3.COOH$ and *p*-$C_6H_4(COOH)_2$ from *p*-$C_6H_4.CH_3.NH_2$.

CHAPTER XXIV

AROMATIC ALCOHOLS, PHENOLS, AND ETHERS

438. The hydroxyl derivatives of the aromatic hydrocarbons may be sharply divided into two classes according to their chemical properties; those of one class resemble closely the aliphatic alcohols, while those of the other possess weakly acidic properties and form salts with aqueous solutions of alkalies. The difference between the two classes of compounds results from the fact that in the aromatic alcohols, such as benzyl alcohol, $C_6H_5CH_2OH$, the hydroxyl group is situated in the side-chain, whereas in the other class of derivatives, which are called phenols, the hydroxyl group is linked to a carbon atom of the ring. Benzyl alcohol may be considered as a substitution-product of methyl alcohol formed as the result of the replacement of one hydrogen atom by a phenyl radical. We can readily understand, therefore, the close relationship in properties which exists between the two compounds. In the case of phenol, the hydroxyl group is linked to a carbon atom of a benzene ring, and we have already seen that the nature of an aryl radical is such that compounds formed by its union with other groups possess certain characteristic properties. In the case of the hydroxyl derivatives, the negative nature of the aryl radical manifests itself in the acidic properties which these derivatives possess.

Aromatic Alcohols

The chemistry of the aromatic alcohols may be well illustrated by a consideration in some detail of a few typical members of the series.

439. Benzyl Alcohol, $C_6H_5CH_2OH$, occurs in the balsam of Peru in the free condition, and in combination as the esters of benzoic acid and cinnamic acid. It is also present in small quantity in the volatile oil of cherry-laurel. The alcohol is a liquid, which possesses a faint odor, is difficultly soluble in water, and boils at 206°.

Benzyl alcohol may be prepared by the methods used in the preparation of aliphatic alcohols. For example, it is formed when benzyl chloride is heated with water: —

$$C_6H_5CH_2Cl + HOH = C_6H_5CH_2OH + HCl$$

As in the case of the aliphatic compounds the rate of the reaction is increased by bringing about the substitution of hydroxyl for chlorine in the presence of potassium carbonate or lead hydroxide.

A method often used in the case of aliphatic compounds can be employed with advantage in the preparation of benzyl alcohol.* The method consists in the conversion of an alkyl halide into an acetate, and the saponification of the latter: —

$$CH_3COONa + ClCH_2C_6H_5 = CH_3COO.CH_2C_6H_5 + NaCl$$
$$CH_3COO.CH_2C_6H_5 + NaOH = CH_3COONa + C_6H_5CH_2OH$$

Benzyl alcohol can also be prepared by reducing benzoic aldehyde with sodium-amalgam and water: —

$$C_6H_5CHO + 2H = C_6H_5CH_2OH$$

It can be prepared from benzoic aldehyde by a reaction which is characteristic of aromatic aldehydes. It will be recalled that alkalies convert aliphatic aldehydes into resins, which are polymerization-products of the aldehydes. A reaction of a different nature takes place with aromatic aldehydes; that with benzoic aldehyde is typical: —

$$2C_6H_5CHO + NaOH = C_6H_5COONa + C_6H_5CH_2OH$$

Through the influence of the alkali two molecules of the aldehyde interact; one molecule is oxidized to the corresponding acid by the second molecule, which, as a result, is reduced to an alcohol. The reaction indicated above takes place when benzoic aldehyde is shaken with an aqueous solution of sodium hydroxide; it furnishes a convenient method of preparing small quantities of benzyl alcohol.

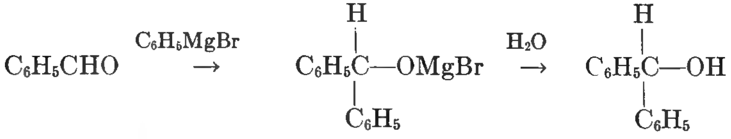
Benzyl alcohol resembles ethyl alcohol in chemical properties. It yields an aldehyde and an alcohol on oxidation, is converted into benzyl chloride by the chlorides of phosphorus, and forms esters with acids. The presence of the phenyl radical affects to some extent the activity of the alcohol. For example, benzyl alcohol is converted into benzyl chloride by cold concentrated hydrochloric acid, whereas ethyl alcohol is not changed under the same conditions. The alcohol does not yield benzyl sulphuric acid when treated with concentrated sulphuric acid, but a resin is formed, which probably results from the elimination of water from the alcohol.

On account of the activity of benzyl alcohol, its derivatives which contain substituents in the ring are prepared indirectly. Thus, *m*-nitrobenzyl alcohol is not formed when benzyl alcohol is treated with nitric acid. It is prepared by the action of sodium hydroxide on *m*-nitrobenzoic aldehyde.

440. Diphenylcarbinol (benzhydrol), $(C_6H_5)_2CHOH$, is an example of a secondary aromatic alcohol. It resembles in chemical properties the analogous aliphatic alcohols, but the presence of the two aryl radicals brings about an activity which is not observed among the derivatives of the paraffins. Diphenylcarbinol is made most conveniently by reducing benzophenone with zinc and an alcoholic solution of potassium hydroxide: —

$$(C_6H_5)_2CO + 2H = (C_6H_5)_2CHOH$$

Diphenylcarbinol may be prepared by the Grignard reaction. The steps involved in the preparation are indicated by the following formulas: —



$$C_6H_5CHO \xrightarrow{C_6H_5MgBr} C_6H_5\overset{\displaystyle H}{\underset{\displaystyle C_6H_5}{C}}—OMgBr \xrightarrow{H_2O} C_6H_5\overset{\displaystyle H}{\underset{\displaystyle C_6H_5}{C}}—OH$$

This method has been of service in the preparation of a number of compounds analogous to diphenylcarbinol.

Diphenylcarbinol melts at 68° and boils at 298°. Oxidizing agents convert it into benzophenone, and a concentrated solution of hydrochloric acid into diphenylchlormethane.

441. Triphenylcarbinol, $(C_6H_5)_3COH$, possesses the properties characteristic of a tertiary alcohol. Like other compounds of this class, it is converted into a chloride when treated with acid chlorides, and not into an ester: —

$$(C_6H_5)_3COH + CH_3COCl = (C_6H_5)_3CCl + CH_3COOH$$

Triphenylcarbinol can be prepared by oxidizing triphenylmethane: —

$$(C_6H_5)_3CH + O = (C_6H_5)_3COH$$

The preparation is carried out by heating a solution of the hydrocarbon in acetic acid with chromic acid. This method of preparing a tertiary alcohol is limited in its application to the aromatic series.

The alcohol is conveniently prepared by heating triphenylchlormethane (**409**) with water: —

$$(C_6H_5)_3CCl + HOH = (C_6H_5)_3COH + HCl$$

Triphenylcarbinol melts at 159°, and boils without decomposition above 360°.

442. Cinnamyl Alcohol, $C_6H_5.CH=CH.CH_2OH$, may be taken as an example of the unsaturated aromatic alcohols. It occurs in storax as the ester of cinnamic acid, $C_6H_5CH=CH_2COOH$. It crystallizes in needles, which possess an odor like that of hyacinths, melts at 33°, and boils at 254°.

The chemical properties of the alcohol are in accord with the structure assigned to it. It is converted by reduction into phenylpropyl alcohol: —

$$C_6H_5.CH:CH.CH_2OH + 2H = C_6H_5.CH_2.CH_2.CH_2OH$$

The product formed when the alcohol is oxidized is determined by the oxidizing agent used. Air in the presence of platinum-black gives cinnamic aldehyde: —

$$C_6H_5.CH:CH.CH_2OH + O = C_6H_5.CH_2:CH_2.CHO + H_2O$$

and chromic acid gives cinnamic acid and benzoic acid: —

$$C_6H_5.CH:CH.CH_2OH + 2O = C_6H_5.CH:CH.COOH + H_2O$$
$$C_6H_5.CH:CH.CH_2OH + 7O = C_6H_5COOH + 2CO_2 + 2H_2O$$

Cinnamic acid is formed as the result of the oxidation of a primary alcohol group to the carboxyl group, and benzoic acid as the result of the complete oxidation of the side-chain.

PHENOLS

443. The phenols are not made by the methods used in the preparation of alcohols, as halogen atoms linked to carbon atoms of the benzene ring can not, in general, be replaced readily by hydroxyl groups. The difference between alkyl and aryl halides is not one of kind but of degree. Brombenzene may be converted into phenol, but the reaction is one which is brought about only as the result of very energetic action. In order to replace the halogen atom by a hydroxyl group it is necessary to heat brombenzene with sodium methylate in a sealed tube at 220°.

Phenols are prepared from sulphonic acids or amines. When the sodium salt of benzenesulphonic acid, for example, is fused with sodium hydroxide, it is converted into the salt of phenol: —

$$C_6H_5SO_3Na + 2NaOH = C_6H_5ONa + Na_2SO_3$$

Phenol is obtained by treating the product of the fusion with an acid: —

$$C_6H_5ONa + HCl = C_6H_5OH + NaCl$$

The reaction is one which is extensively used in the preparation of compounds of this class.

Phenols are also prepared from primary amines by means of the diazo reaction: —

$$C_6H_5NH_3Cl + HNO_2 = C_6H_5N_2Cl + 2H_2O$$
$$C_6H_5N_2Cl + HOH = C_6H_5OH + N_2 + HCl$$

444. **Chemical Properties of Phenols.** — Phenols exhibit the behavior of hydroxyl compounds when treated with the substances which react with the hydroxyl group. They react with acyl chlorides and acid anhydrides. Phenol and acetyl chloride, for example, react to form phenyl acetate and hydrogen chloride:

$$CH_3COCl + HOC_6H_5 = CH_3COOC_6H_5 + HCl$$

The hydroxyl group of phenols can be replaced by halogen by means of the halides of phosphorus: —

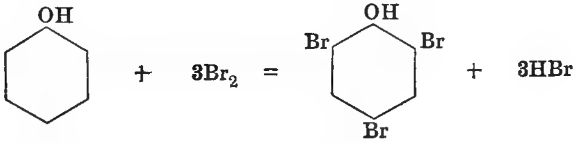
$$C_6H_5OH + PCl_5 = C_6H_5Cl + POCl_3 + HCl$$

The yield of chloride obtained in this way is small, however, as the chief product of the reaction consists of esters of phosphoric acid and compounds formed by the replacement of one or more halogen atoms by the C_6H_5O group. The compounds formed when phosphorus trichloride is used, have the formulas $(C_6H_5O)_3P$, $(C_6H_5O)_2PCl$, and $(C_6H_5O)PCl_2$. It will be recalled that similar reactions take place when the hydroxyl groups of alcohols are replaced by halogen by means of the halides of phosphorus, but the reactions do not interfere, as they do in the case of phenols, with the use of the halides of phosphorus in the preparation of halogen derivatives.

Salts of phenols react with alkyl halides to form ethers: —

$$C_6H_5OK + C_2H_5I = C_6H_5OC_2H_5 + KI$$

Substitution-products of phenols are readily prepared, the presence of the hydroxyl group facilitating markedly the introduction of atoms or groups. An aqueous solution of bromine converts phenol into symmetrical tribromphenol: —



Dilute nitric acid gives *o*-nitrophenol and *p*-nitrophenol, and the concentrated acid symmetrical trinitrophenol.

Phenols are reduced to hydrocarbons when passed over heated zinc-dust: —

$$C_6H_5OH + Zn = C_6H_6 + ZnO$$

It has been stated that phenols are weak acids, and that their acidic property probably results from the fact that the aryl group which they contain is negative. The negative nature of the phenyl group is not highly developed, and, as a consequence, phenol is a very weak acid; its salts are decomposed by carbonic acid. The extent to which acetic acid, carbonic acid, and phenol dissociate in one-tenth normal solution is 1.3, 0.174, and 0.0037 per cent, respectively, whereas at this concentration hydrochloric acid is dissociated to the extent of over 90 per cent. Notwithstanding the fact that phenols are such weak acids, they dissolve readily in alkalies. As they are weaker than carbonic acid, they are not soluble in carbonates. This fact is made use of in the separation of acids from phenols.

The negative nature of the phenyl radical is increased as the result of the replacement of the hydrogen atoms which it contains by negative atoms or groups. Trinitrophenol is a comparatively strong acid, which readily decomposes carbonates.

445. Phenol, C_6H_5OH, occurs in coal-tar, from which it is obtained commercially. It is found in the urine in small quantities in combination with sulphuric acid as phenylsulphuric acid, $C_6H_5SO_4H$. It is a colorless substance, which crystallizes in long needles, melts at 43°, and boils at 183°. Phenol, sometimes called carbolic acid, has a characteristic odor, and on account of its strong antiseptic properties was formerly much used in surgery. Phenol dissolves in about 15 parts of water at 16°. Water is slightly soluble in phenol. The presence of even a small amount of water lowers the freezing-point of phenol below the ordinary temperature.

The more important reactions of phenol have been given in the section above. Phenol is a poison, and has a corrosive action on the skin. Ferric chloride produces a violet coloration in a dilute aqueous solution of phenol. It is of interest to note that phenol has been prepared from benzene by the action of oxygen in the presence of palladium-black or aluminium chloride.

446. Cresols, $CH_3.C_6H_4.OH$. — The three hydroxyl derivatives of toluene are found along with other phenols in the *creosote* obtained from coal-tar, and the tars from pine and beech wood. As it is difficult to separate the isomeric cresols they are prepared in the pure condition from the toluenesulphonic acids or the toluidines.

o-Cresol (m.p. 30°, b.p. 191°) and *p*-cresol (m.p. 36°, b.p. 202°) are decomposition-products of proteins. The ortho compound has been found in combination with sulphuric acid in the urine of horses, and the para compound in the urine of man.

447. Carvacrol and **Thymol**, $CH_3.C_3H_7.C_6H_3.OH$, are phenols derived from cymene (*p*-methyl-*i*-propylbenzene). In carvacrol the hydroxyl group is ortho to the methyl radical; this is shown by the fact that carvacrol is converted into *o*-cresol and propylene when heated with phosphorus pentoxide. In thymol the hydroxyl group is ortho to isopropyl.

Carvacrol occurs with cymene in a number of essential oils. It can be prepared by heating camphor with iodine. Thymol occurs in the oil of thyme and the oil of mint. It has germicidal properties, but is less active and less poisonous than phenol.

448. Naphthols, $C_{10}H_7OH$. — The naphthols are prepared by fusing the isomeric naphthalenesulphonic acids with alkalies. They crystallize in plates, have a phenolic odor, and are sparingly soluble in water. α-Naphthol melts at 95° and boils at 282°; β-naphthol melts at 122° and boils at 288°. Although the naphthols possess the properties of phenols, the hydroxyl groups which they contain are more readily replaceable by other groups than is the hydroxyl group of phenol. For example, when β-naphthol is heated with the compound of calcium chloride and ammonia it is converted into β-naphthylamine.

When ferric chloride is added to a solution of β-naphthol a green coloration and a precipitate of β-dinaphthol, $HO.C_{10}H_6.C_{10}H_6.OH$, are formed; with α-naphthol a violet precipitate, which is probably an iron compound of α-dinaphthol, results. β-Naphthol is used as an antiseptic.

449. Pyrocatechol, pyrocatechin, catechol, $C_6H_4(OH)_2$ (1, 2), occurs in the leaves and sap of certain plants, in raw beet sugar, and in many resins. It is obtained by heating guaiacol, $C_6H_4.OH.OCH_3$ (1, 2), which is a constituent of beechwood tar, with hydriodic acid. It is also prepared by fusing *o*-phenol sulphonic acid with potassium hydroxide at 350°. Pyrocatechol is readily soluble in water, from which it crystallizes in needles, which melt at 104°.

An alkaline solution of pyrocatechol absorbs oxygen from the air, and turns green and then black. The solution precipitates the metals from salts of silver, gold, and platinum; on account of this fact it is used as a photograph developer. An aqueous solution of the phenol is colored green by ferric chloride. When an alkali is added to the solution the color changes to red, as the result of the formation of a salt of the composition $Na_3Fe(C_6H_4O_2)_3.2H_2O$. The iron in this compound is not precipitated by bases. As the radical of pyrocatechol is bivalent the salt resembles in composition sodium ferricyanide, $Na_3Fe(CN)_6$.

450. **Resorcinol**, resorcin, $C_6H_4(OH)_2(1, 3)$, is prepared technically by fusing *m*-benzenedisulphonic acid with caustic soda. It is also formed when *m*-iodophenol or *p*-chlorbenzenesulphonic acid is fused with potassium hydroxide. The preparation of resorcinol from these compounds illustrates two important points: first, that a halogen atom in direct combination with the benzene ring may be replaced by hydroxyl, and second, that in effecting the replacement of one group by another by means of fusion with an alkali, the relative positions of the groups in the resulting compound may not be those of the groups in the substance used in the synthesis. Many ortho, meta, and para compounds yield resorcinol when fused with caustic alkalies. This unexpected result is not in accord with one of the important principles made use of in the determination of structure, and led to much confusion in the early study of organic chemistry.

Resorcinol crystallizes from water in colorless plates or prisms, which melt at 118°, and turn red in the air. It gives a deep violet coloration with a solution of ferric chloride. The phenol is not as strong a reducing agent as pyrocatechol.

Resorcinol is used in the manufacture of certain dyes. When heated with sodium nitrite it yields a blue dye, called *lacmoid*, which is turned red by acids.

451. **Quinol**, hydroquinone, $C_6H_4(OH)_2(1, 4)$, may be obtained from arbutin, which is a glucoside of quinol, by hydrolysis with dilute acids, or by the action of emulsin. It is prepared by reducing quinone, $C_6H_4O_2$ (**492**), by means of sulphur dioxide.

Quinol is readily soluble in water, from which it crystallizes in prisms which melt at 169°. It can be sublimed unchanged. An aqueous solution of quinol slowly turns brown when exposed to the air and loses its reducing power. As a reducing agent it is intermediate between pyrocatechol and resorcinol. An alkaline solution of quinol is a valuable photographic developer. Oxidizing agents convert quinol into quinone; the reaction will be considered later (**492**). When ferric chloride is added to an aqueous solution of the phenol, quinhydrone (**492**) separates in lustrous green spangles. On adding an excess of ferric chloride the quinhydrone is converted into quinone.

452. Pyrogallol, pyrogallic acid, $C_6H_3(OH)_3(1, 2, 3)$, is the most important of the isomeric trihydroxybenzenes. It is obtained by heating gallic acid (**522**):—

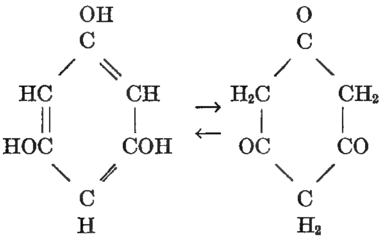
$$C_6H_2(OH)_3COOH = C_6H_3(OH)_3 + CO_2$$

It is readily soluble in water, crystallizes in colorless plates, which melt at 132°, and can be sublimed without decomposition. It is an energetic reducing agent, and is used as a photographic developer. An alkaline solution of pyrogallic acid absorbs oxygen from the air and rapidly turns brown. Such solutions are used in the determination of oxygen in gas analysis.

453. Phloroglucinol, phloroglucin, $C_6H_3(OH)_3(1, 3, 5)$, was first obtained from the glucoside phloridizin. It has also been isolated from other glucosides and from certain resins. It is formed when resorcinol, orcinol (3, 5-dihydroxytoluene), or 1, 3, 5-benzene-trisulphonic acid is fused with sodium hydroxide. The formation of phloroglucinol from resorcinol is an illustration of a reaction which often takes place in fusion with alkalies, namely, the replacement of a hydrogen atom by a hydroxyl group. The formation of the phenol from orcinol under the same conditions, is effected as the result of the replacement of an alkyl radical by hydroxyl. Under certain conditions alkyl radicals joined to the benzene ring are converted into carboxyl groups when the compounds which contain the radical are fused with alkalies. *p*-Toluenesulphonic acid may be converted in this way into *p*-hydroxybenzoic acid. These illustrations indicate that fused alkalies are active reagents which serve to bring about many important transformations in aromatic compounds.

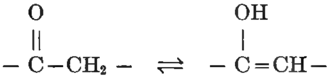
Phloroglucinol melts at 219°, and tastes sweet. An aqueous solution of the phenol is colored bluish-violet by ferric chloride.

454. Many of the reactions of phloroglucinol are in accord with the view that it is a trihydroxyl derivative of benzene. With certain reagents, however, it reacts as if it were a ketone, which contains three carbonyl groups. For example, one molecule of phloroglucinol reacts with three molecules of hydroxylamine, and a compound is formed which has the properties characteristic of oximes. These facts are explained by the hypothesis that the compound can exist in the two tautomeric forms represented by the following formulas: —



Trihydroxybenzene   Triketohexamethylene

The behavior of phloroglucinol with reagents is analogous to that of other tautomers. When brought into contact with reagents which interact with hydroxyl derivatives, it reacts as if it contained this group, and with certain substances which interact with ketones, it acts as if it belonged to the latter class of compounds. This view of the structure of phloroglucinol furnishes an explanation of the fact that when a solution of the phenol in potassium hydroxide is treated with alkyl iodides, compounds are formed in which the alkyl radicals are linked to carbon. The relation between the two forms of phloroglucinol is similar to that between the *enol* and *keto* forms of aceto-acetic ester. It will be recalled that when the sodium derivative of the *enol* form of the ester is treated with alkyl halides, the product of the reaction is a derivative of the *keto* form in which the alkyl group introduced is linked to carbon. Tautomerism is shown by many compounds which contain the group $-CO-CH_2-$, the rearrangement taking place as indicated below: —



$$-\overset{\overset{\displaystyle O}{\|}}{C}-CH_2- \;\rightleftharpoons\; -\overset{\overset{\displaystyle OH}{|}}{C}=CH-$$

The trihydroxybenzene which has the unsymmetrical structure $C_6H_3(OH)_3(1, 3, 4)$ is called hydroxyquinol. It can be prepared by fusing quinol with potassium hydroxide. Like pyrogallol it does not react with hydroxylamine.

455. Hexahydroxybenzene, $C_6(OH)_6$, is obtained from its potassium salt, which is formed by passing carbon monoxide over heated potassium: —

$$6CO + 6K = C_6(OK)_6$$

The compound forms colorless crystals, which are readily oxidized by the air. It is converted into benzene when distilled with zinc-dust.

456. Identification of Phenols. — The reactions of phenols which are of particular value in their identification, are those that take place with alkalies, ferric chloride, and bromine water. Most phenols react with an aqueous solution of sodium hydroxide to form soluble salts, but are insoluble in a solution of sodium carbonate. The behavior of phenols with these two reagents shows their weakly acidic properties, and serves to distinguish them from acids. Phenols which contain strongly negative substituents decompose carbonates, and show all the properties of acids. It is difficult, therefore, to identify as a phenol substances which contain such substituents. Ferric chloride produces marked colorations in aqueous solutions of most phenols. The reagent produces a similar effect with certain other compounds, and the formation of a color with ferric chloride can be taken, therefore, only as an indication of the presence of a phenol. With bromine water most phenols yield a precipitate of a brominated phenol. Other compounds, amines for example, are also converted into insoluble substitution-products by bromine water. Notwithstanding this fact the test is of value. Many phenols form colored products when heated with phthalic anhydride and concentrated sulphuric acid. The reaction will be described under phenolphthalein (**473**).

ETHERS

457. The aromatic ethers may be divided into two classes, viz., those which contain an aryl and an alkyl radical, and those which contain two aryl radicals. The ethers of the first class resemble closely the analogous aliphatic compounds, and can be made by similar methods.

Anisol, phenyl methyl ether, $C_6H_5OCH_3$, can be prepared by treating a solution of phenol in potassium hydroxide with methyl iodide: —

$$C_6H_5OK + CH_3I = C_6H_5OCH_3 + KI$$

In the preparation in this way the halogen is removed from an aliphatic compound, and the reaction takes place readily. In order to prepare anisol from brombenzene by the reaction,

$$C_6H_5Br + NaOCH_3 = C_6H_5OCH_3 + NaBr$$

it is necessary to heat the mixture for a long time in a sealed tube at 220°. The two reactions show very clearly the difference in reactivity between alkyl and aryl halides. Anisol is a liquid of ethereal odor, which boils at 155°.

Anisol is also formed by a reaction which is characteristic of the aromatic series, namely, the decomposition of a diazonium salt with an alcohol: —

$$C_6H_5N_2Cl + CH_3OH = C_6H_5OCH_3 + N_2 + HCl$$

Like aliphatic ethers, the aromatic ethers are stable compounds; they are decomposed, however, when heated with hydriodic acid: —

$$C_6H_5OCH_3 + HI = C_6H_5OH + CH_3I$$

458. Phenetol, phenyl ethyl ether, $C_6H_5OC_2H_5$, boils at 172°, the boiling-point being lower than that of phenol.

The ethers which contain two aryl radicals can not be made by the general method employed to prepare other ethers, as the aryl halides do not react with the salts of phenols. *Phenyl ether* is obtained by heating phenol with anhydrous zinc chloride:

$$C_6H_5\underline{OH + H}OC_6H_5 = C_6H_5OC_6H_5 + H_2O$$

Phenyl ether is a very stable compound. It is not decomposed when heated with hydriodic acid to a high temperature. Phenyl ether melts at 28° and boils at 253°.

PROBLEMS

1. Write equations for reactions by which the following may be prepared through use of the Grignard reaction: (*a*) $C_6H_5.CH_3.CHOH$, (*b*) $C_6H_5.(CH_3)_2.COH$, (*c*) $(C_6H_5)_2.CH_3.COH$.

2. By what chemical tests could the following be distinguished from each other: (*a*) $C_6H_4.CH_3.OH$ and $C_6H_5.CH_2OH$, (*b*) $C_6H_4.CH_3.OH$ and $C_6H_5OCH_3$, (*c*) $C_6H_4.CH_3.OC_6H_5$ and $C_6H_4.C_6H_5.OCH_3$, (*d*) $C_6H_4.CH_3.OH$ and $C_6H_4.CH_3.COOH$, (*e*) $C_6H_4.NH_2.OH$ and $C_6H_4.NO_2.OH$, (*f*) $C_6H_4.OCH_3.COOH$ and $C_6H_4.OH.COOCH_3$?

3. By what chemical reactions could you distinguish from one another the following: $C_6H_5CH_2CH_2CH_2OH$ and $C_6H_5CH=CH.CH_2OH$; $C_6H_4.CH=CH_2.CH_2OH$ and $C_6H_4.OH.CH_2CH_3$?

4. Identify the compound which gave the following results: The substance contained nitrogen, melted at about 184°, and was slightly soluble in

water. It dissolved readily in a solution of sodium hydroxide from which it was precipitated on the addition of hydrochloric acid. On further addition of acid the compound dissolved. The substance did not react with a solution of sodium carbonate, but was converted by acetyl chloride into a derivative which melted at 179°.

CHAPTER XXV

AROMATIC ACIDS

459. The aromatic acids resemble closely in chemical properties the acids derived from the paraffins, and yield similar derivatives. On account of the negative nature of the phenyl radical they are stronger than the fatty acids. The ionization constant of benzoic acid, $C_6H_5.COOH$, for example, is 0.0060, while that of acetic acid is 0.0018.

The presence of a benzene ring in these acids makes it possible to prepare from them many derivatives which are characteristic of aromatic compounds. Benzoic acid is converted into nitrobenzoic acid by nitric acid and into sulphobenzoic acid by sulphuric acid.

A large number of aromatic acids occur in nature in the free condition and as esters in resins, balsams, and the oils extracted from plants. They also occur in the animal organism in combination with nitrogenous substances. The acids are, in general, colorless and crystalline, difficultly soluble in water, and may be distilled or sublimed unchanged. Those which contain a number of carboxyl or hydroxyl groups decompose when heated to a high temperature; gallic acid, $C_6H_2(OH)_3COOH$, for example, loses carbon dioxide when heated, and is converted into pyrogallol, $C_6H_3(OH)_3$.

460. Preparation of Aromatic Acids. — The aromatic acids may be formed by methods which are analogous to those used in the preparation of fatty acids. Aromatic alcohols and aldehydes yield acids on oxidation: —

$$C_6H_5.CH_2OH + 2O = C_6H_5.COOH + H_2O$$
$$C_6H_5.CHO + O = C_6H_5.COOH$$

These methods are seldom used as the acids can be prepared more conveniently in other ways.

Acids are frequently made by hydrolyzing nitriles: —

$$C_6H_5.CN + 2H_2O = C_6H_5.COOH + NH_3$$
$$C_6H_5.CH_2.CN + 2H_2O = C_6H_5.CH_2.COOH + NH_3$$

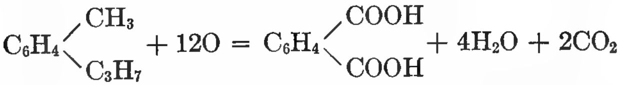
Nitriles which contain the CN group in the side-chain are prepared as in the aliphatic series; those in which the group is linked to the nucleus are formed by means of the diazo reaction. This later method of preparing acids is an important one, as by means of it, a nitro or an amino group may be replaced by carboxyl.

Acids which contain the carboxyl group in a side-chain may be prepared by the acetoacetic ester synthesis.

Another important method is limited in its application to the preparation of acids which contain the carboxyl group in direct combination with the nucleus. Aromatic acids of this type may be prepared by oxidizing aromatic hydrocarbons which contain side-chains. When toluene, for example, is heated with a solution of chromic acid, it is converted into benzoic acid: —

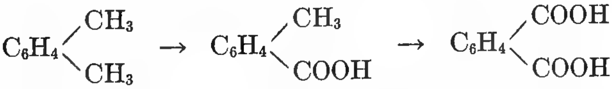
$$C_6H_5.CH_3 + 3O = C_6H_5.COOH + H_2O$$

All side-chains, whatever their length, are converted by active oxidation into carboxyl groups: —



$$C_6H_4\begin{array}{l}\diagup CH_3 \\ \diagdown C_3H_7\end{array} + 12O = C_6H_4\begin{array}{l}\diagup COOH \\ \diagdown COOH\end{array} + 4H_2O + 2CO_2$$

It is possible under certain circumstances to bring about the oxidation of the side-chains one after another. When *p*-xylene is heated with dilute nitric acid one methyl group is oxidized; chromic acid oxidizes both groups. It is thus possible to effect the transformations indicated by the following formulas: —



$$C_6H_4\begin{array}{l}\diagup CH_3 \\ \diagdown CH_3\end{array} \rightarrow C_6H_4\begin{array}{l}\diagup CH_3 \\ \diagdown COOH\end{array} \rightarrow C_6H_4\begin{array}{l}\diagup COOH \\ \diagdown COOH\end{array}$$

Aromatic acids may also be prepared by fusing a salt of a sulphonic acid with sodium formate: —

$$C_6H_5.SO_3Na + H.COONa = C_6H_5.COONa + NaHSO_3$$

461. Chemical Properties of Aromatic Acids. — The aromatic acids take part in the reactions which are characteristic of the carboxyl group. They are converted, for example, into acyl halides by the halides of phosphorus,—

$$C_6H_5.COOH + PCl_5 = C_6H_5.COCl + POCl_3 + HCl$$

and form esters when heated with alcohols in the presence of hydrogen chloride or sulphuric acid: —

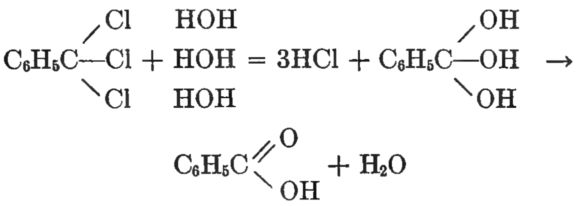
$$C_6H_5.COOH + C_2H_5OH = C_6H_5.COOC_2H_5 + H_2O$$

Like other aromatic compounds, they may be converted into nitro derivatives, sulphonic acids, and halogen derivatives. The presence of the negative carboxyl group makes it more or less difficult to introduce a negative substituent into the ring. While toluene, $C_6H_5.CH_3$, is readily sulphonated by warming the hydrocarbon with concentrated sulphuric acid on a water-bath, benzoic acid, $C_6H_5.COOH$, is converted into a sulphonic acid by heating it with fuming sulphuric acid or sulphur trioxide. The carboxyl group, like other strongly negative groups, sends a substituent to the meta position; benzoic acid yields on sulphonation *m*-sulphobenzoic acid, $HSO_3.C_6H_4.COOH$, whereas toluene yields *p*-toluensulphonic acid, $CH_3.C_6H_4.SO_3H$.

MONOBASIC ACIDS AND THEIR DERIVATIVES

462. Benzoic Acid, $C_6H_5.COOH$, occurs in gum-benzoin, in many resins, in the balsams of Peru and Tolu, in cranberries, in coal-tar, and in combination with glycine as hippuric acid in the urine of herbivorous animals. It may be made by the general synthetic methods which have been described. It is prepared for use in pharmacy by sublimination from gum-benzoin. It is manufactured on the large scale from toluene, and is a by-product in the preparation of benzaldehyde. Toluene is converted by direct oxidation into benzoic acid. As benzyl chloride, $C_6H_5.CH_2Cl$, is more readily oxidized than toluene, the latter is first treated with chlorine, and then heated with dilute nitric acid.

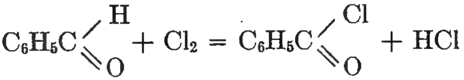
Benzoic acid is also made from benzotrichloride, $C_6H_5.CCl_3$, which is prepared by passing chlorine into boiling toluene. When the halogen compound is heated with lime and water under pressure, the chlorine atoms are replaced by hydroxyl groups: —



$$C_6H_5C\begin{matrix}/Cl\\ -Cl\\ \backslash Cl\end{matrix} + \begin{matrix}HOH\\ HOH\\ HOH\end{matrix} = 3HCl + C_6H_5C\begin{matrix}/OH\\ -OH\\ \backslash OH\end{matrix} \rightarrow C_6H_5C\begin{matrix}/\!\!/O\\ \backslash OH\end{matrix} + H_2O$$

Benzoic acid is used in medicine, in the preparation of aniline-blue, and for other purposes. Sodium benzoate is much used as a food-preservative. The acid melts at 121.4°, boils at 250°, and sublimes readily. It crystallizes from hot water in glistening plates or flat needles, and is volatile with steam.

463. Benzoyl Chloride, $C_6H_5.COCl$, can be prepared by the action of phosphorus pentachloride on benzoic acid or sodium benzoate. It is made on the large scale from benzoic aldehyde:



$$C_6H_5C\begin{matrix}/H\\ \backslash\!\!\backslash O\end{matrix} + Cl_2 = C_6H_5C\begin{matrix}/Cl\\ \backslash\!\!\backslash O\end{matrix} + HCl$$

Benzoyl chloride is a liquid of disagreeable odor, which is insoluble in water, and boils at 194°. It resembles acetyl chloride in its behavior, but does not enter into reaction so readily. It is decomposed but slowly by cold water or alcohol. The reaction between benzoyl chloride and alcohols is much facilitated by the presence of an alkali. Ethyl benzoate may be prepared by shaking an aqueous solution of alcohol and sodium hydroxide with benzoyl chloride (Baumann and Schotten reaction): —

$$C_6H_5.COCl + HOC_2H_5 + NaOH = C_6H_5.COOC_2H_5 + NaCl + H_2O$$

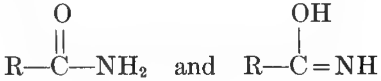
464. Benzoic Anhydride, $(C_6H_5CO)_2O$, can be prepared by the methods used to make acetic anhydride: —

$$C_6H_5.COCl + C_6H_5COONa = (C_6H_5CO)_2O + NaCl$$
$$4C_6H_5COONa + POCl_3 = 2(C_6H_5CO)_2O + NaPO_3 + 3NaCl$$

The anhydride resembles acetic anhydride, but it is less active. It is converted slowly into benzoic acid by boiling water. It is insoluble in water, and melts at 42°.

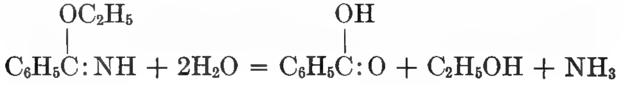
465. Benzamide, $C_6H_5CO.NH_2$, is formed when benzoyl chloride is treated with ammonium carbonate or an aqueous solution of ammonia. It crystallizes from hot water in glistening plates which melt at 130°.

In discussing the structure of the aliphatic amides (**179**) it was stated that their reactions indicate that they may exist in the two forms —

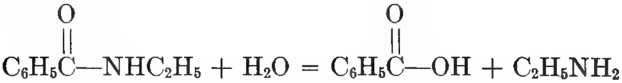


$$R-\overset{O}{\overset{\|}{C}}-NH_2 \quad \text{and} \quad R-\overset{OH}{\overset{|}{C}}=NH$$

Certain derivatives of benzamide tend to confirm this view. When the silver salt of benzamide is treated with ethyl iodide, the metal is replaced by the alkyl radical. The product formed is determined by the temperature at which reaction takes place. The substance obtained at room-temperature yields ammonia and alcohol when heated with an alkali, while that formed at 100° yields ethylamine. The formulas of the substances and their decomposition are represented by the following equations: —



$$C_6H_5\overset{OC_2H_5}{\overset{|}{C}}:NH + 2H_2O = C_6H_5\overset{OH}{\overset{|}{C}}:O + C_2H_5OH + NH_3$$



$$C_6H_5\overset{O}{\overset{\|}{C}}-NHC_2H_5 + H_2O = C_6H_5\overset{O}{\overset{\|}{C}}-OH + C_2H_5NH_2$$

466. Benzonitrile, $C_6H_5.CN$, can be prepared by a method used to make acetonitrile, namely, the removal of water from benzamide. The method most commonly used in the preparation of the nitriles of aromatic acid is an application of the diazo reaction (**429**). Benzonitrile is a liquid with an odor resembling that of the oil of bitter almonds. It boils at 191°, and is converted into benzoic acid when heated with a mixture of one part of water and three parts of sulphuric acid.

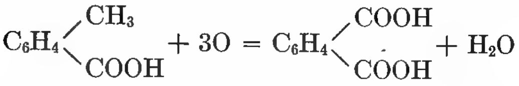
467. Toluic Acids, $CH_3.C_6H_4.COOH$. — The three toluic acids can be prepared by the oxidation of the three xylenes with nitric acid, or from the toluidines, $CH_3.C_6H_4.NH_2$, by converting them by means of the diazo reaction into nitriles, which on hydrolysis are converted into toluic acids. The acids are crystalline substances, which are difficultly soluble in water. The ortho, meta, and para acids melt at 102°, 110°, and 180°, respectively.

468. Phenylacetic Acid, $C_6H_5.CH_2.COOH$, is isomeric with the toluic acids. It is prepared by hydrolyzing benzyl cyanide (b.p. 232°), which is formed by the action of potassium cyanide on benzyl chloride: —

$$C_6H_5.CH_2Cl + KCN = C_6H_5.CH_2CN + KCl$$
$$C_6H_5.CH_2.CN + 2H_2O = C_6H_5.CH_2.COOH + NH_3$$

Phenylacetic acid crystallizes in lustrous plates and melts at 76°. It is converted by oxidizing agents into benzoic acid, whereas the isomeric toluic acids are converted into phthalic acids: —

$$C_6H_5CH_2COOH + 3O = C_6H_5COOH + CO_2 + H_2O$$



$$C_6H_4\begin{matrix}\diagup CH_3\\ \diagdown COOH\end{matrix} + 3O = C_6H_4\begin{matrix}\diagup COOH\\ \diagdown COOH\end{matrix} + H_2O$$

Phenylacetic acid yields derivatives which contain substituents in either the side-chain or the nucleus. The methods by which the two classes of derivatives may be prepared are applications of the principles which have been discussed. The reactions by which the two chlorine substitution-products are formed are examples: —

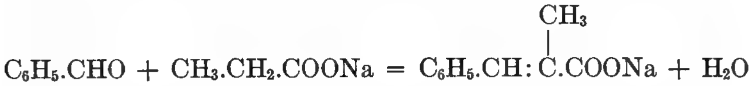
$$C_6H_5.CHOH.COOH + HCl = C_6H_5.CHCl.COOH + H_2O$$
$$ClC_6H_4.CH_2.CN + 2H_2O = ClC_6H_4.CH_2.COOH + NH_3$$

469. Cinnamic Acid, $C_6H_5.CH{=}CH.COOH$, is the most important member of the class of unsaturated aromatic acids. It occurs in oil of cinnamon, the balsams of Peru and Tolu, gum-benzoin, storax, and the leaves of certain plants. The acid crystallizes from hot water, melts at 134°, and boils with partial decomposition at 300°.

Cinnamic acid is manufactured by the so-called Perkin synthesis, which has been applied to the preparation of a large number of unsaturated acids. When benzoic aldehyde is heated with anhydrous sodium acetate in the presence of acetic anhydride, condensation takes place as the result of the loss of water:

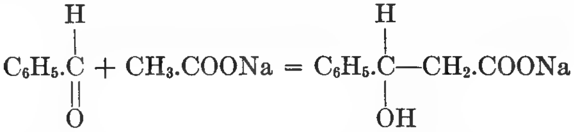
$$C_6H_5.CHO + CH_3.COONa = C_6H_5.CH:CH.COONa + H_2O$$

A similar condensation takes place between benzoic aldehyde and homologues of acetic acid. The hydrogen atoms which are eliminated from the salt of the fatty acid are those in the α-position: —



$$C_6H_5.CHO + CH_3.CH_2.COONa = C_6H_5.CH:\overset{\overset{CH_3}{|}}{C}.COONa + H_2O$$

It has been shown that the formation of unsaturated acids by the Perkin synthesis takes place as the result of two reactions. The aldehyde and the salt first form an addition-product, which resembles in structure other addition-products of aldehydes: —



$$C_6H_5.\overset{\overset{H}{|}}{\underset{\underset{O}{\|}}{C}} + CH_3.COONa = C_6H_5.\overset{\overset{H}{|}}{\underset{\underset{OH}{|}}{C}}—CH_2.COONa$$

In the addition, one hydrogen atom unites with the oxygen and the rest of the molecule with carbon. The second step in the reaction involves the removal of water from a β-hydroxyacid. It will be recalled that such acids readily lose water and pass into unsaturated acids: —

$$C_6H_5.CHOH.CH_2COONa = C_6H_5CH:CH.COONa + H_2O$$

Cinnamic acid can also be prepared by heating benzal chloride with sodium acetate — a method which is applied commercially:

$$C_6H_5.CHCl_2 + CH_3COONa = C_6H_5.CH:CH.COOH + NaCl + HCl$$

Cinnamic acid, like other unsaturated compounds, forms addition-products with the halogen hydrides, hypochlorous acid, bromine, and so forth. It yields esters, an acid chloride, and an amide. The hydrogen atoms in the benzene ring may be replaced by the halogens, nitro groups, amino groups, and the sulphonic acid group.

470. Phenylpropiolic Acid, $C_6H_5.C{\equiv}C.COOH$, may be prepared from cinnamic acid by the reactions which are commonly employed to establish a triple bond in a compound. It is obtained by adding bromine to the ethyl ester of cinnamic acid, and subsequent elimination of hydrogen bromide by alcoholic potassium hydroxide: —

$$C_6H_5.CH{:}CH.COOC_2H_5 + Br_2 = C_6H_5.CHBr.CHBr.COOC_2H_5,$$
$$C_6H_5.CHBr.CHBr.COOC_2H_5 + 3KOH = C_6H_5.C{\vdots}C.COOK + 2KBr + 2H_2O + C_2H_5OH$$

Phenylpropiolic acid melts at 137° and crystallizes in needles, which can be sublimed. When heated with water at 120° it loses carbon dioxide, and phenylacetylene is formed: —

$$C_6H_5.C{\vdots}C.COOH = C_6H_5.C{\vdots}CH + CO_2$$

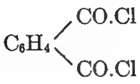
DIBASIC ACIDS AND THEIR DERIVATIVES

471. The dibasic acids derived from benzene are the most important members of this class. They are called phthalic acids on account of the fact that the first of them discovered was prepared from naphthalene. The chemistry of the aromatic dibasic acids is similar to that of the analogous fatty compounds. In addition to the chemical properties possessed by the latter, the phthalic acids possess the properties characteristic of aromatic compounds, that is, they may be nitrated, sulphonated, and chlorinated.

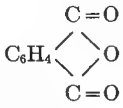
Phthalic Acid, $C_6H_4(COOH)_2(1, 2)$, is formed when benzene derivatives which contain two side-chains in the ortho position, are oxidized by dilute nitric acid or potassium permanganate. Chromic acid can not be used, as it oxidizes ortho compounds completely to carbon dioxide and water. The acid is prepared on the large scale from naphthalene, and is used in the preparation of artificial indigo. The hydrocarbon is oxidized by heating it with concentrated sulphuric acid in the presence of mercuric sulphate, which serves as a catalytic agent.

Phthalic acid crystallizes from hot water. It does not possess a definite melting-point, as it slowly decomposes into its anhydride and water when heated. Melting-points can be obtained from 180° to 213°, the higher temperatures being observed when the acid is heated rapidly.

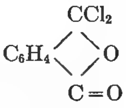
472. Phthalyl Chloride is formed when phthalic acid or its anhydride is treated with phosphorus pentachloride. Its reactions indicate that its structure is not that of a normal chloride, which is represented by the first formula given below, but that it is formed as the result of the replacement by chlorine of an oxygen atom in one of the carbonyl groups of phthalic anhydride: —

(1) 

$C_6H_4\begin{cases}CO.Cl\\CO.Cl\end{cases}$

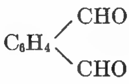
(2) 

Phthalic anhydride

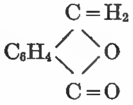
(3) 

Phthalyl chloride

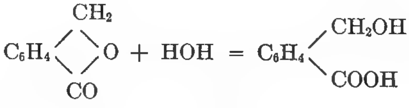
When phthalyl chloride is treated with sodium amalgam and water, the halogen atoms are replaced by hydrogen. If the structure of the chloride were that represented by formula (1) the resulting compound would be a dialdehyde (formula 4 below). The product formed does not show the properties of an aldehyde, but enters into reactions which are explicable on the assumption that it is derived from a chloride which has the constitution represented by formula (3). The compound is called *phthalide*, and has the structure indicated by formula (5),

(4) 

$C_6H_4\begin{cases}CHO\\CHO\end{cases}$

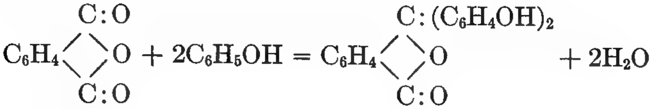
(5) 

Phthalic aldehyde (formula 4) has been prepared by boiling the compound of the structure $C_6H_4(CHCl_2)_2$ with a solution of sodium hydroxide; it possesses the properties characteristic of aldehydes. The structure of phthalide follows from the fact that it is converted by hydrolysis into a hydroxymethylbenzoic acid: —



Phthalide appears to be, therefore, a lactone.

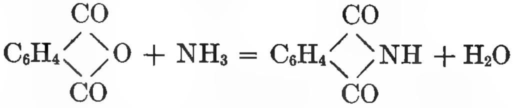
473. Phthalic Anhydride, $C_6H_4(CO)_2O$, is formed when phthalic acid is heated. It sublimes in long needles which melt at 128°. When heated with phenols in the presence of a dehydrating agent, phthalic anhydride forms characteristic compounds, called phthaleins, which give highly colored solutions when dissolved in alkalies. The reaction in the case of phenol is indicated by the following equation: —



$$C_6H_4\begin{array}{c} C{:}O \\ \langle\ \rangle O \\ C{:}O \end{array} + 2C_6H_5OH = C_6H_4\begin{array}{c} C{:}(C_6H_4OH)_2 \\ \langle\ \rangle O \\ C{:}O \end{array} + 2H_2O$$

The hydrogen atoms involved in the condensation are those in the position para to the hydroxyl group of the phenol. Phenolphthalein is sparingly soluble in water and is colorless. It dissolves in alkalies to form salts, which are deep red in color. It is much used as an indicator in titrating acids and bases. Its structure will be considered in the chapter on dyes (**543**).

474. Phthalimide, $C_6H_4(CO)_2NH$, is obtained by passing ammonia over heated phthalic anhydride: —



$$C_6H_4\begin{array}{c} CO \\ \langle\ \rangle O \\ CO \end{array} + NH_3 = C_6H_4\begin{array}{c} CO \\ \langle\ \rangle NH \\ CO \end{array} + H_2O$$

It crystallizes from ether in prisms, which melt at 228°. The imide is of interest on account of its use in the preparation of aliphatic amines. When phthalimide is treated in alcoholic solution with potassium hydroxide, a metallic derivative of the imide is precipitated. This salt interacts with alkyl halides to form compounds which are produced as the result of the replacement of the metal by the alkyl radicals. The substances formed in this way yield a primary amine on hydrolysis. The transformations involved are indicated by the following formulas: —

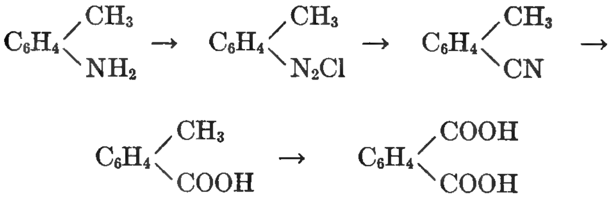
$$C_6H_4(CO)_2NK \xrightarrow{RI} C_6H_4(CO)_2NR \xrightarrow{NaOH} C_6H_4(COONa)_2 + H_2NR$$

It is possible to prepare in this way a great variety of primary amines, since substitution-products of the alkyl halides, such as those of the formulas $CH_2Br.CH_2.CH_2Br$, and $CH_2OH.CH_2Br$, can be used in the synthesis.

475. Isophthalic Acid, $C_6H_4(COOH)_2(1, 3)$, may be formed from a large number of meta substitution-products of benzene. It has been prepared by fusing the potassium salt of *m*-benzenesulphonic acid with sodium formate, by the action of sodium and ethyl chlorcarbonate on *m*-dibrombenzene, by the oxidation of *m*-toluic acid, and in other ways. It is most conveniently prepared by oxidizing *m*-xylene with a solution of potassium bichromate and sulphuric acid. As in the oxidation of other hydrocarbons, the conversion of side-chains into carboxyl groups proceeds more readily if a part of the hydrogen which they contain be replaced by halogen. In the preparation of isophthalic acid from *m*-xylene, the hydrocarbon is first heated with bromine at 125°, and the resulting substitution-product, $C_6H_4(CH_2Br)_2$, is then oxidized.

Isophthalic acid crystallizes from hot water in needles, which melt at about 300°. It does not form an anhydride when heated.

476. Terephthalic Acid, $C_6H_4(COOH)_4$(1, 4), can be formed from a number of para substitution-products of benzene. It is conveniently prepared from *p*-toluidine by the transformations indicated by the following formulas: —



$$C_6H_4\left\langle\begin{matrix}CH_3\\NH_2\end{matrix}\right. \rightarrow C_6H_4\left\langle\begin{matrix}CH_3\\N_2Cl\end{matrix}\right. \rightarrow C_6H_4\left\langle\begin{matrix}CH_3\\CN\end{matrix}\right. \rightarrow$$

$$C_6H_4\left\langle\begin{matrix}CH_3\\COOH\end{matrix}\right. \rightarrow C_6H_4\left\langle\begin{matrix}COOH\\COOH\end{matrix}\right.$$

Terephthalic acid is obtained as a powder, which is almost insoluble in water and in alcohol. It sublimes unchanged without melting. The property of certain dibasic acids of forming anhydrides when heated, is limited to those acids which contain two carboxyl groups in the positions ortho to each other.

477. Mellitic Acid, $C_6(COOH)_6$, is of interest as it contains six carboxyl groups. It occurs in peat as the aluminium salt, which is called honey-stone, $C_6(COO)_6Al_2.18H_2O$. The acid is formed as the result of the oxidation of lignite, wood-charcoal, or graphite with potassium permanganate. It crystallizes in silky needles, and is not affected when treated with nitric acid, sulphuric acid, or bromine. Benzene is formed when the calcium salt of mellitic acid is heated with lime.

PROBLEMS

1. Write equations for reactions by which aromatic acids may be prepared by means of (*a*) the oxidation of a hydrocarbon, (*b*) the hydrolysis of a nitrile, and the use of the following syntheses (*c*) acetoacetic ester, (*d*) malonic ester, (*e*) Perkin, (*f*) Grignard, (*g*) Friedel and Crafts (through the use of $COCl_2$).

2. Write equations for reactions by which the following acids may be prepared by means of the Perkin synthesis: (*a*) $CH_3C_6H_4.CH=CH.COOH$, (*b*) $C_6H_5CH=C(COOH)_2$, (*c*) $C_6H_5.CH=C.C_2H_5.COOH$, (*d*) $C_6H_5.CH=C(CH_2.COOH)COOH$.

3. Write equations for reactions by which (*a*) o-$C_6H_4(COOH)_2$ may be converted into o-$C_6H_4.CH_2OH.COOH$, (*b*) $C_6H_5.CH_3$ into p-$C_6H_4(COOH)_2$, (*c*) $C_6H_5(CO)_2NH$ into o-$C_6H_5.CONH_2.COOH$, (*d*) $C_6H_5.CH_2.COOH$ into $C_6H_5.COOH$.

4. Applying the rules for substitution (**381**) indicate by equations how the following may be prepared: (*a*) $C_6H_3.CH_3.COOH.NO_2(1,2,4)$, (*b*) m-$C_6H_4.NO_2.COOH$, (*c*) p-$C_6H_4.NO_2.COOH$, (*d*) p-$C_6H_4.NH_2.SO_3H$, (*e*) m-$C_6H_4.NH_2.COOH$.

5. A hydrocarbon of the formula $C_{10}H_{14}$ was converted by careful oxidation into the compound $C_8H_8O_2$ and by active oxidizing agents into the compound $C_8H_6O_4$. Write a possible formula for the hydrocarbon.

CHAPTER XXVI

AROMATIC ALDEHYDES, KETONES, AND QUINONES

478. The aromatic aldehydes are formed by reactions analogous to those made use of in the preparation of aliphatic aldehydes. The method which is best adapted to the preparation of the aromatic compounds is not the same as that used most conveniently in the aliphatic series. Acetic aldehyde and its homologues are usually prepared by oxidizing primary alcohols. Benzoic aldehyde, a typical aromatic aldehyde, is manufactured by heating benzal chloride, prepared from toluene, with water in the presence of lime: —

$$C_6H_5.CHCl_2 + H_2O = C_6H_5.CHO + 2HCl$$

Acetic aldehyde can be formed in a similar way from ethylidene chloride, $CH_3.CHCl_2$, but its preparation by this reaction lacks practical value. There is marked difference between the ease with which benzal chloride and ethylidene chloride react with water; the presence of the phenyl radical in the former brings about an activity not shown by the aliphatic halide. The choice of the compounds used in the preparation of the two classes of aldehydes is determined, to some extent, by the substances which can be obtained conveniently and at a low price. The alcohols are, in general, the starting-point for the preparation of many aliphatic compounds, on account of their reactivity and the fact that they are prepared commercially on a large scale. In the aromatic series, on the other hand, the hydrocarbons are of the greatest importance as a source of other compounds.

The aromatic aldehydes resemble in chemical properties the analogous fatty compounds; but their behavior with certain reagents is unique, and they enter into a number of reactions of condensation which are of prime importance. A description of a typical aldehyde will suffice to illustrate the properties of the members of the class.

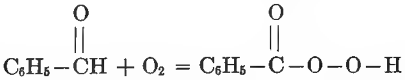
479. Benzaldehyde, benzoic aldehyde, $C_6H_5.CHO$, occurs in amygdalin, a glucoside which is present in bitter almonds and in the kernels of various fruits; it yields the aldehyde, hydrocyanic acid, and glucose on hydrolysis (**285**). The aldehyde is called oil of bitter almonds. It is used in flavoring extracts and perfumery, in the manufacture of certain dyes, and in the preparation of other compounds.

Benzaldehyde is a liquid with an agreeable odor, which boils at 179°, and has the specific gravity 1.0504 at 15°. It can be formed by oxidizing benzyl alcohol, or distilling calcium benzoate with calcium formate. It is manufactured by heating benzal chloride with milk of lime, or by oxidizing benzyl chloride with a solution of lead nitrate.

Benzaldehyde may be made from toluene by a method described by Étard, which has proved of particular value in the preparation of a number of its derivatives. When chromyl chloride, CrO_2Cl_2, is slowly added to a solution of toluene in carbon bisulphide, a compound of the formula $C_6H_5CH_3.2CrO_2Cl_2$ is precipitated. The addition-product yields benzaldehyde when cautiously decomposed by water.

Benzaldehyde shows most of the reactions which are characteristic of aliphatic aldehydes. It reduces an ammoniacal solution of silver nitrate, forms addition-products with acid sodium sulphite and with hydrocyanic acid, is converted by nascent hydrogen into an alcohol, and yields an oxime and a phenylhydrazone.

480. Benzaldehyde is oxidized when exposed to the air, the reaction taking place more rapidly in the presence of sunlight. It has been shown that the first product formed is benzoyl hydrogen peroxide, which results from the direct addition of one molecule of the aldehyde and one molecule of oxygen: —



$$C_6H_5-\overset{\overset{\large O}{\|}}{C}H + O_2 = C_6H_5-\overset{\overset{\large O}{\|}}{C}-O-O-H$$

The peroxide so formed is an active oxidizing agent, and interacts with benzaldehyde to form benzoic acid: —

$$C_6H_5.CO.O.OH + C_6H_5.CHO = 2C_6H_5.COOH$$

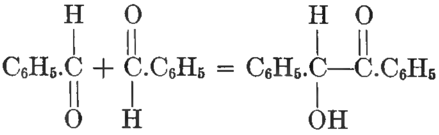
That an active oxidizing agent is formed during the oxidation of benzaldehyde by air, has been shown by adding to the aldehyde some oxidizable substance which is unaffected by free oxygen. The substance is oxidized and the amount of oxygen which reacts with it is equal to that used in converting the aldehyde into benzoic acid. One-half of the oxygen absorbed is thus rendered "active," that is, it has the properties of so-called nascent oxygen, being able to oxidize substances which are unaffected by molecular oxygen. The phenomenon has been observed in the oxidation by air of various substances. Generally in such oxidations a molecule of oxygen is added to the compound, and a peroxide is formed, which, in certain cases, readily gives up a part of its oxygen to substances capable of undergoing oxidation.

481. In its reactions with alkalies and with ammonia, benzaldehyde does not resemble the aliphatic aldehydes. While the latter are polymerized to resins by alkalies, benzaldehyde and its homologues are converted by the reagent into alcohols and acids: —

$$2C_6H_5.CHO + KOH = C_6H_5.CH_2OH + C_6H_5.COOK$$

One molecule of aldehyde oxidizes a second molecule to an acid, and is, as a result, reduced to an alcohol.

The aromatic aldehydes do not polymerize in the way which is characteristic of aliphatic aldehydes. Under certain conditions, however, two molecules of an aldehyde unite and form stable derivatives of dibenzyl. When benzaldehyde is heated in dilute alcoholic solution in the presence of potassium cyanide, benzoin (**497**) is formed: —



$$C_6H_5.\underset{\underset{\displaystyle O}{\|}}{\overset{\overset{\displaystyle H}{|}}{C}} + \underset{\underset{\displaystyle H}{|}}{\overset{\overset{\displaystyle O}{\|}}{C}}.C_6H_5 = C_6H_5.\underset{\underset{\displaystyle OH}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle O}{\|}}{C}.C_6H_5$$

The union of the two molecules is effected as the result of the breaking of the double bond of one of the carbonyl groups; a hydrogen atom adds to the oxygen, and the rest of the molecule to the carbon atom.

Benzaldehyde does not form an addition-product with ammonia. When allowed to stand some days with a strong aqueous solution of ammonia, hydrobenzamide is formed: —

$$3C_6H_5.CHO + 2NH_3 = (C_6H_5.CH)_3N_2 + 3H_2O$$

Hydrobenzamide is insoluble in water, and crystallizes from alcohol in octahedra, which melt at 110°.

When benzaldehyde is treated with chlorine, benzoyl chloride is formed: —

$$C_6H_5.CHO + Cl_2 = C_6H_5.COCl + HCl$$

The reaction is used in the technical preparation of benzoyl chloride. The derivatives of benzaldehyde which contain a halogen atom in the ring, are prepared from substitution-products of benzal chloride: —

$$Cl.C_6H_4.CHCl_2 + H_2O = Cl.C_6H_4.CHO + 2HCl$$

Benzaldehyde is converted by fuming sulphuric acid into *m*-sulphobenzoic aldehyde, —

$$C_6H_5.CHO + H_2SO_4 = HSO_3.C_6H_4.CHO$$

and by fuming nitric acid into *m*-nitrobenzaldehyde. As the aldehyde group sends an entering group to the meta position, ortho and para derivatives of the aldehyde are prepared by indirect methods. *o*-Nitrobenzaldehyde is prepared by the careful oxidation of *o*-nitrocinnamic acid, $NO_2.C_6H_4CH{=}CH.COOH$; *p*-nitrobenzaldehyde may be made in a similar way or from *p*-nitrotoluene by means of Étard's method.

482. Benzaldehyde takes part in a number of important condensations. When shaken with concentrated sulphuric acid and aromatic hydrocarbons, derivatives of triphenylmethane are formed: —

$$C_6H_5.CHO + 2C_6H_5CH_3 = C_6H_5.CH(C_6H_4CH_3)_2 + H_2O$$

In the presence of dehydrating agents, such as zinc chloride, similar condensation-products are formed from phenols and aromatic amines: —

$$C_6H_5.CHO + 2C_6H_5N(CH_3)_2 = C_6H_5.CH[C_6H_4N(CH_3)_2]_2 + H_2O$$

Benzaldehyde condenses with aliphatic compounds in an analogous manner; the Perkin synthesis (**469**) is an example: —

$$C_6H_5.CHO + CH_3.COONa = C_6H_5CH{:}CH.COONa + H_2O$$

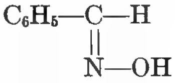
In the presence of a solution of sodium hydroxide benzaldehyde condenses with aliphatic aldehydes and ketones: —

$$C_6H_5.CHO + CH_3.CO.CH_3 = C_6H_5CH{:}CH.CO.CH_3$$

483. Benzaldoxime, $C_6H_5.CH.NOH$, is of special interest as it exists in two forms. When benzaldehyde is warmed with hydroxylamine an oxime is formed, which melts at 35°: —

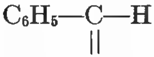
$$C_6H_5.CHO + H_2NOH = C_6H_5.CH:NOH + H_2O$$

This substance is converted by hydrogen chloride into a salt which yields an isomer of benzaldoxime when decomposed by sodium carbonate. The isomer melts at 128°–130°, shows the properties of an oxime, and slowly changes into the original oxime when heated. The two substances are considered to be stereo-isomers, the relation between the two forms being analogous to that between the *syn* and *anti* diazoates: —



$$\begin{array}{ccc} C_6H_5— & C & —H \\ & \| & \\ & N & —OH \end{array}$$

synaldoxime



$$\begin{array}{ccc} C_6H_5— & C & —H \\ & \| & \\ HO— & N & \end{array}$$

antialdoxime

The two compounds differ in their behavior with acetic anhydride; the one which melts at 128°–130° loses water and passes into benzonitrile, whereas the isomer yields an acetyl derivative, which is formed as the result of the replacement of the hydrogen atom of the hydroxyl group by acetyl. For this reason the more stable, low-melting compound is considered to be benzantialdoxime. It is highly probable that the synaldoxime, in which the hydrogen atom and hydroxyl group are on the same side of the molecule, would lose water more readily than its isomer.

484. Cuminic Aldehyde, $i\text{-}C_3H_7.C_6H_4.CHO(1,4)$, occurs in the oil of caraway and in other essential oils. It is a liquid of characteristic odor, which boils at 237.5°. It may be isolated from essential oils by treating the latter with sodium hydrogen sulphite, and decomposing the difficultly soluble addition-product of the aldehyde and sulphite by distilling it with a solution of sodium carbonate. Aldehydes are usually isolated in this way from the mixtures containing them which occur in nature.

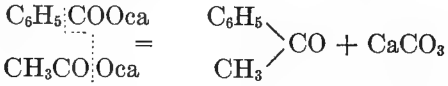
485. Cinnamic Aldehyde, $C_6H_5.CH=CH.CHO$, occurs in oil of cinnamon, oil of cassia, and other essential oils. It may be isolated from these sources through the preparation of its addition-product with acid sodium sulphite. It is prepared by condensing benzaldehyde with acetaldehyde in the presence of a dilute solution of sodium hydroxide: —

$$C_6H_5.CHO + CH_3.CHO = C_6H_5.CH:CH.CHO + H_2O$$

Cinnamic aldehyde possesses the chemical properties characteristic of aldehydes and of unsaturated compounds. It forms an addition-product with bromine, which readily loses hydrogen bromide. It boils at 129° (20 mm.).

KETONES

486. Acetophenone, $C_6H_5.CO.CH_3$. — The aromatic ketones may be prepared by methods which are analogous to those used in the preparation of aliphatic ketones. Acetophenone, for example, is formed when a mixture of calcium benzoate and calcium acetate is distilled: —



$$\begin{matrix} C_6H_5COOca \\ CH_3COOca \end{matrix} = \begin{matrix} C_6H_5 \\ CH_3 \end{matrix}\!\!>CO + CaCO_3$$

The aromatic ketones are most conveniently prepared by means of the Friedel and Crafts reaction from acyl chlorides and aromatic hydrocarbons: —

$$CH_3COCl + C_6H_6 \overset{AlCl_3}{=} CH_3COC_6H_5 + HCl$$

Acetophenone melts at 20.5°, boils at 202°, and is slightly soluble in water. It is used in medicine as a hypnotic under the name *hypnone.*

The reactions of acetophenone are analogous, in general, to those of the aliphatic ketones. It reacts with hydroxylamine, phenylhydrazine, and hydrocyanic acid, but does not form an addition-product with sodium hydrogen sulphite. It is converted into calcium benzoate and chloroform when warmed with a solution of bleaching-powder, the reaction being analogous to that between bleaching-powder and acetone. Acetophenone is converted by phosphorus pentoxide or hydrogen chloride into triphenylbenzene, the condensation being similar to that in which mesitylene is formed from acetone (**357**). When acetophenone is treated with chlorine or bromine the hydrogen atoms in the methyl radical are replaced by halogen.

Acetophenone possesses the properties characteristic of aromatic compounds. When heated with dilute nitric acid it is oxidized to benzoic acid; with concentrated nitric acid nitro derivatives are formed. The chief product of nitration is *m*-nitroacetophenone; a small proportion of the ortho compound is also formed. *p*-Nitroacetophenone can be prepared from *p*-nitrobenzoyl chloride and acetoacetic ester.

487. Benzophenone, $C_6H_5.CO.C_6H_5$, is most conveniently prepared by condensing benzoyl chloride with benzene by means of the Friedel and Crafts reaction; the way in which the reaction takes place has already been described in detail (**348**).

Benzophenone melts at 48° and boils without decomposition at 306.1°. When the ketone is formed as the result of the oxidation of diphenylmethane and certain other substances, it is obtained, at times, in a form which melts at 27°. The difference between the two forms is not the result of a difference in structure. The low-melting variety readily passes into the ordinary form when treated with a trace of the latter. The difference in melting-point and crystalline structure may be the result of a difference in molecular aggregation. It will be recalled that sulphur, phosphorus, and other elements exist in a variety of forms.

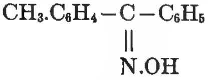
Benzophenone may be reduced to diphenylcarbinol and to diphenylmethane: —

$$(C_6H_5)_2CO \quad \rightarrow \quad (C_6H_5)_2CHOH \quad \rightarrow \quad (C_6H_5)_2CH_2$$

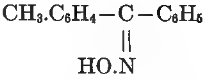
The carbinol is formed when an alcoholic solution of the ketone is boiled with zinc-dust and potassium hydroxide. As in the case of acetone, the ketone is reduced to a secondary alcohol by alkaline reducing agents. When benzophenone is heated to a high temperature with hydriodic acid and red phosphorus it is reduced to the hydrocarbon.

Benzophenone may be nitrated, sulphonated, and chlorinated. It dissolves in concentrated sulphuric acid, and is precipitated unchanged when the solution is poured into water. The ketone forms colored addition-products with aluminium chloride, ferric chloride, and stannic chloride.

488. Ketoximes. — This name is given to the oximes derived from ketones. Benzophenone yields but one oxime, but certain derivatives of benzophenone of the general formula R.CO.R′ in which R and R′ are different radicals, yield oximes which exist in two forms. The isomerism appears to be stereochemical and to result from the fact that the oximes contain a carbon atom linked by a double bond to a nitrogen atom. The formulas of the two oximes of tolyphenyl ketone are as follows: —

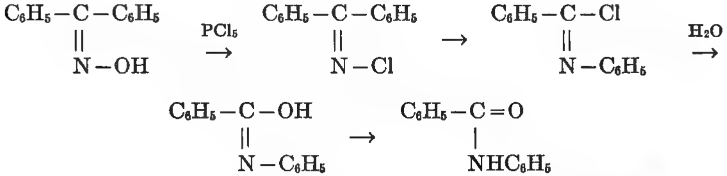


$$\begin{array}{c} CH_3.C_6H_4-C-C_6H_5 \\ \| \\ N.OH \end{array}$$



$$\begin{array}{c} CH_3.C_6H_4-C-C_6H_5 \\ \| \\ HO.N \end{array}$$

When ketoximes are treated with phosphorus pentachloride and then with water, they undergo a molecular transformation which is known as "the Beckmann rearrangement." Benzophenoneoxime is converted in this way into benzanilide. The steps involved in the change are probably those indicated below: —

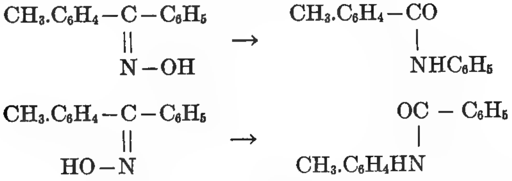


$$\begin{array}{c} C_6H_5-C-C_6H_5 \\ \| \\ N-OH \end{array} \xrightarrow{PCl_5} \begin{array}{c} C_6H_5-C-C_6H_5 \\ \| \\ N-Cl \end{array} \rightarrow \begin{array}{c} C_6H_5-C-Cl \\ \| \\ N-C_6H_5 \end{array} \xrightarrow{H_2O}$$

$$\begin{array}{c} C_6H_5-C-OH \\ \| \\ N-C_6H_5 \end{array} \rightarrow \begin{array}{c} C_6H_5-C=O \\ | \\ NHC_6H_5 \end{array}$$

The steps involved in the reaction can be readily understood. Phosphorus pentachloride acts normally on the oxime and replaces a hydroxyl group by chlorine. In the resulting compound chlorine is joined to a trivalent nitrogen atom. Compounds which contain these elements in combination are unstable, and, as a consequence, a molecular rearrangement takes place in which the halogen atom and aryl group change places. The resulting compound on decomposition with water yields the unstable tautomeric form of anilides, which rearranges into the stable form.

By applying the Beckmann rearrangement to stereo-isomeric oximes, it is possible to determine the formula which should be assigned to each form of the oxime. The transformations in the case of the two oximes of phenyltolyl ketone are indicated by the following formulas: —



$$\begin{array}{c} CH_3.C_6H_4-C-C_6H_5 \\ \| \\ N-OH \end{array} \rightarrow \begin{array}{c} CH_3.C_6H_4-CO \\ | \\ NHC_6H_5 \end{array}$$

$$\begin{array}{c} CH_3.C_6H_4-C-C_6H_5 \\ \| \\ HO-N \end{array} \rightarrow \begin{array}{c} OC-C_6H_5 \\ | \\ CH_3.C_6H_4HN \end{array}$$

The oxime of the structure indicated by the first formula, yields, as the result of undergoing the Beckmann rearrangement, the anilide of toluic acid,

$CH_3.C_6H_4CO.NHC_6H_5$, while its isomer is converted by a similar transformation into the toluide of benzoic acid, $C_6H_5CO.NHC_6H_4.CH_3$.

Ketones which contain two very dissimilar radicals, such as acetophenone, $C_6H_5.CO.CH_3$, do not yield isomeric oximes.

489. Benzalacetone, $C_6H_5CH{=}CH.CO.CH_3$, is an example of an unsaturated aromatic ketone. It is prepared by allowing benzoic aldehyde and acetone to stand in contact with a dilute solution of sodium hydroxide: —

$$C_6H_5.CHO + CH_3.CO.CH_3 = C_6H_5.CH{:}CH.CO.CH_3 + H_2O$$

The condensation is analogous to that by which cinnamic acid is prepared from benzoic aldehyde and sodium acetate, although in the latter case a dehydrating agent is required to bring about the elimination of water. Benzalacetone melts at 42°, and possesses the properties of an unsaturated compound and of a ketone.

When acetone is treated with two molecules of benzaldehyde, dibenzalacetone, which crystallizes in yellow plates (m.p. 121°), is formed: —

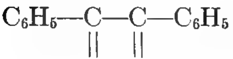
$$2C_6H_5.CHO + (CH_3)_2CO = (C_6H_5CH{:}CH)_2CO + 2H_2O$$

490. Benzil, $C_6H_5.CO.CO.C_6H_5$, is an aromatic diketone. It is most conveniently prepared by oxidizing benzoin (**497**) with nitric acid: —

$$C_6H_5.CHOH.CO.C_6H_5 + O = C_6H_5.CO.CO.C_6H_5 + H_2O$$

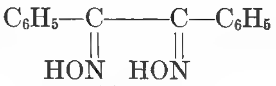
Benzil crystallizes from alcohol in yellow needles which melt at 95°. It takes part in many reactions which are characteristic of ketones. It may be reduced to desoxybenzoin, $C_6H_5.CH_2.CO.C_6H_5$, benzoin, $C_6H_5.CHOH.CO.C_6H_5$, and to hydrobenzoin, $C_6H_5.CHOH.CHOH.C_6H_5$.

The dioxime of benzil exists in the three stereo-isomeric forms represented by the following formulas: —



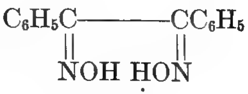
$$\begin{matrix} C_6H_5- & C & - & C & -C_6H_5 \\ & \Vert & & \Vert & \\ & HON & & NOH & \end{matrix}$$

antioxime



$$\begin{matrix} C_6H_5- & C & \text{——} & C & -C_6H_5 \\ & \Vert & & \Vert & \\ & HON & & HON & \end{matrix}$$

amphioxime

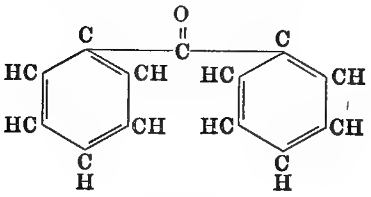


$$\begin{matrix} C_6H_5 & C & \text{————} & C & C_6H_5 \\ & \Vert & & \Vert & \\ & NOH & & HON & \end{matrix}$$

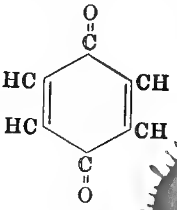
synoxime

QUINONES

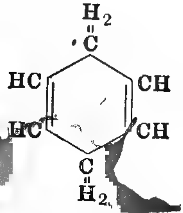
491. It has been repeatedly pointed out that the chemical properties of substitution-products of aromatic hydrocarbons which contain a substituent in the side-chain, are markedly different from those of isomeric compounds in which the substituent is linked to a carbon atom of the ring. The fact is especially noticeable in the case of compounds which contain the carbonyl, C=O, group. In the ketones, the oxygen atom is joined by two bonds to a carbon atom which is outside of the ring. Compounds are known in which an oxygen atom is joined by two bonds to a carbon atom of the ring; they are called quinones and differ markedly in properties from ketones. The relation between the structures of a ketone, quinone, and dihydrobenzene is shown by the following formulas: —



ketone



quinone



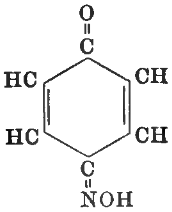
dihydrobenzene

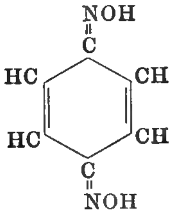
A carbon atom in a benzene ring can hold in combination but one atom of a univalent element, as three of its bonds are involved in the ring-formation peculiar to benzene. In order to form a compound in which one of the carbon atoms of the nucleus is joined by two bonds to a bivalent element, it is necessary to bring into play the latent affinities of the carbon atoms. As a consequence, the peculiar neutralization of the fourth bonds of the atoms of the ring, which is characteristic of benzene, is destroyed; and the resulting compound is a derivative of dihydrobenzene. The quinones contain two carbonyl groups, which may be either ortho or para to each other. The quinone which has been fully studied is the para compound.

492. Quinone, $C_6H_4O_2$, is also called benzoquinone to indicate that it is the quinone related to benzene. It crystallizes in yellow needles, which melt at 116°, has a peculiar, pungent odor, and is volatile with steam with partial decomposition.

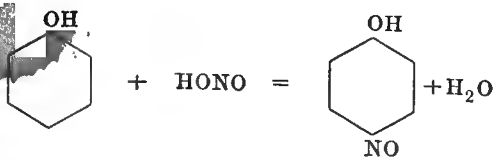
Quinone is obtained by the partial oxidation of many para-derivatives of benzene, such as quinol, $C_6H_4(OH)_2$, *p*-aminophenol, $NH_2.C_6H_4.OH$, sulphanilic acid, $NH_2.C_6H_4.SO_3H$, and *p*-phenolsulphonic acid, $HO.C_6H_4.SO_3H$. It is prepared by oxidizing aniline with an aqueous solution of potassium bicromate and sulphuric acid.

Quinone reacts with hydroxylamine to form a monoxime and a dioxime. This fact indicates that it contains two carbonyl groups which possess the properties of the carbonyl group in the ketones. The formulas assigned to the oximes are as follows: —



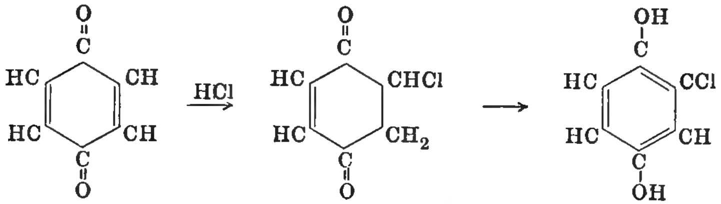


The monoxime is also formed by the action of nitrous acid on phenol; its preparation in this way indicates that the compound i[illegible]trosophenol: —



Some of the reactions of the compound lead to the view that it is an oxime, and others to the view that it is a phenol. With an excess of hydroxylamine it is converted into the dioxime — a fact in favor of the oxime formula; when oxidized in alkaline solution by potassium ferricyanide, *p*-nitrophenol is formed — a fact which is best explained on the assumption that the compound is *p*-nitrosophenol.

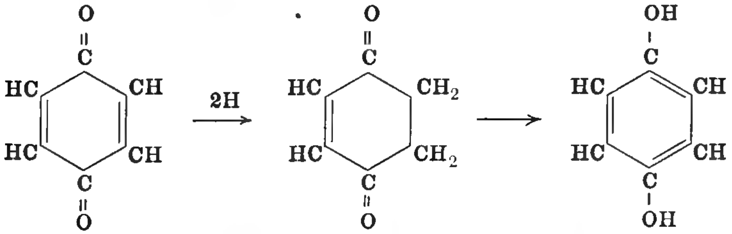
Quinone possesses the properties of an unsaturated compound; it unites with two or with four atoms of bromine when treated in chloroform solution with the halogen. This fact is in accord with the view that quinone is a derivative of dihydrobenzene, which is a highly unsaturated compound. It also unites with hydrogen chloride; the compound formed is chlorquinol. The reaction is assumed to take place in the manner indicated by the following formulas: —



According to this view, the addition-product first formed undergoes rearrangement, which consists in the change of the group $-\overset{\overset{\displaystyle O}{\|}}{C}-CHCl-$ into the group $-\overset{\overset{\displaystyle OH}{|}}{C}=CCl-$. It will be recalled that similar rearrangements take place in acetoacetic ester and analogous compounds.

When quinone is treated with chlorine, substitution takes place and tetrachlorquinone, called chloranil, is formed.

Quinone is reduced to quinol by sulphurous acid, hydriodic acid, and other reducing agents. The explanation of the way in which the change takes place is that indicated by the following formulas: —



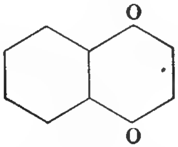
Quinone forms with a number of compounds addition-products, the structures of which have not been established. *p*-Nitraniline, for example, yields a compound of the formula

$C_6H_4O_2.C_6H_4(NO_2)NH_2$, which forms red crystals. The addition-product with quinol, called *quinhydrone*, $C_6H_4O_2.C_6H_4(OH)_2$, is of interest as it is an intermediate-product formed in the oxidation of quinol to quinone by ferric chloride and other oxidizing agents. Quinhydrone forms brownish-red prisms with a green metallic luster.

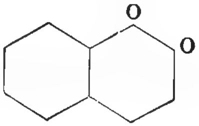
The quinones are colored substances. It is thought that the color is the result of the peculiar molecular structure which these compounds possess. The constitution of many colored substances is best explained by the hypothesis that they contain the so-called "quinoid" configuration. The relation between color and structure will be discussed in the chapter on dyes.

o-Benzoquinone has been prepared by oxidizing *o*-dihydroxybenzene with silver oxide. *m*-Dihydroxybenzene does not yield a quinone.

493. ***α*-Naphthoquinone**, $C_{10}H_6O_2$, is formed by the oxidation of many *α*-derivatives of naphthalene. It is most conveniently prepared by oxidizing a solution of naphthalene in acetic acid with chromic acid. It should be noted that benzoquinone can not be prepared by the direct oxidation of benzene. *α*-Naphthoquinone has a pungent odor, sublimes readily, and crystallizes in yellow needles which melt at 125°. It resembles benzoquinone in chemical properties. As it is reduced to 1, 4-dihydroxynaphthalene, and is converted into phthalic acid on oxidation, its structure is that represented by the following formula: —



***β*-Naphthoquinone**, $C_{10}H_6O_2$, is formed by oxidizing 1,2-dihydroxynaphthalene; its structure is that represented by the formula, —

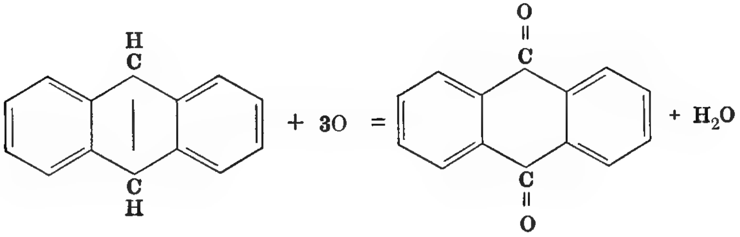


494. Anthraquinone, $C_{14}H_8O_2$, is obtained by oxidizing anthracene with chromic acid or nitric acid: —

$$C_6H_4(CH)_2C_6H_4 + 3O = C_6H_4(CO)_2C_6H_4 + H_2O$$

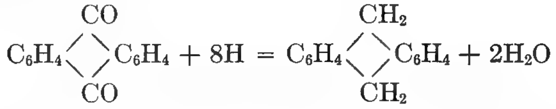
It is formed when calcium benzoate or calcium phthalate is distilled. Anthraquinone crystallizes from hot benzene in yellow prisms or needles, which melt at 273°, boil at 380°, and can be sublimed. It does not show the properties characteristic of quinones and is, therefore, not well named. It is not easily reduced, is not readily volatile, and does not possess a pungent odor.

It has been pointed out that the behavior of quinones is best explained on the view that they are derivatives of dihydrobenzene; and that the ease with which they are reduced and add halogen atoms, is the result of the highly unsaturated nature of the reduced benzene ring. The conversion of anthracene into anthraquinone does not involve the change of a benzene ring into a dihydrobenzene ring. Assuming that anthracene has the structure which has been assigned to it, the oxidation of the hydrocarbon to anthraquinone is best represented by the following formulas: —



In the conversion of anthracene into anthraquinone, the para bond between the two carbon atoms involved in the oxidation is broken, but no change takes place in the benzene rings present in the compound.

This view of the structure of anthraquinone is in accord with the fact that it shows the properties characteristic of ketones. It resembles markedly benzophenone. When anthraquinone is heated with zinc-dust it is reduced to anthracene; phosphorus and hydriodic acid at a high temperature form dihydroanthracene: —



$$C_6H_4\left\langle\begin{matrix}CO\\ CO\end{matrix}\right\rangle C_6H_4 + 8H = C_6H_4\left\langle\begin{matrix}CH_2\\ CH_2\end{matrix}\right\rangle C_6H_4 + 2H_2O$$

Anthraquinone can be converted into nitro derivatives, halogen substitution-products, and sulphonic acids. Many derivatives of anthraquinone are known, some of which are important dyes, and will be discussed later (**535**).

PROBLEMS

1. Summarize the methods of preparation and reactions of aromatic aldehydes.

2. By what reactions may the following be prepared: (*a*) $C_6H_5COCH_2Cl$, (*b*) *p*-$C_6H_4Cl.COCH_3$, (*c*) *o*-$C_6H_4NO_2.CHO$, (*d*) $C_6H_5CH = CHCOC_2H_5$, (*e*) $C_6H_5.CH_2OH$, (*f*) $(C_6H_5)_3CH$ from C_6H_6?

3. Write the graphic formulas of the compounds formed by (*a*) the nitration of *p*-$C_6H_4.CH_3.COCH_3$, (*b*) the reduction of $C_6H_5 = CHCOCH_3$, (*c*) the oxidation of *p*-$C_6H_4Cl.CH_2Cl_2$.

4. Write the structural formulas of the compounds which are formed by applying the Beckmann rearrangement to the stereo-isomeric oximes of $C_6H_5.CO.C_6H_4Cl$.

5. By what reactions can (*a*) *p*-$C_6H_4.CH_3.CHO$ be converted into *p*-$C_6H_4.CH_3.CN$, (*b*) $C_6H_5CH_3$ into *p*-$C_6H_4NO_2.CHO$, (*c*) C_6H_5CHO into $(C_6H_5)_2CO$?

6. By what chemical tests could you distinguish from each other the following: (*a*) $C_6H_5.COCH_2Cl$ and $C_6H_4Cl.COCH_3$, (*b*) $C_6H_4.CH_3.CHO$ and $C_6H_5COCH_3$, (*c*) $C_6H_4NH_2.CHO$ and $C_6H_4NO_2.CHO$ (*d*) $C_3H_7.CHO$ and $C_6H_5.CHO$, (*e*) $(C_6H_{13})_2CO$ and $(C_6H_5)_2CO$?

CHAPTER XXVII

AROMATIC COMPOUNDS CONTAINING TWO OR MORE UNLIKE GROUPS

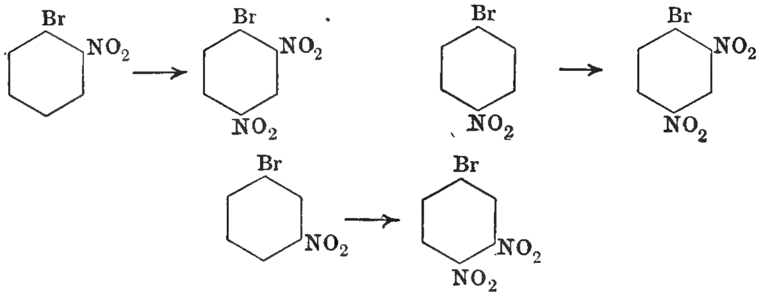
495. Many thousand derivatives of aromatic hydrocarbons containing two or more unlike groups have been prepared. A few compounds of this class have already been described. Only certain typical examples will be discussed here, and those considered will be selected in such a way as to illustrate the methods of preparation and properties of such compounds. The general statement which has been given in regard to the effect of a group in a compound on the position taken by an entering group (**381**), should be reviewed at this point, as it will be seen that the conclusions summarized in this statement serve as a most valuable guide in devising methods to prepare a compound of a given structure.

NITRO-HALOGEN DERIVATIVES

496. **Nitrobrombenzenes**, $Br.C_6H_4.NO_2$.— Three compounds of this formula exist. When brombenzene is nitrated, the bromine atom sends the nitro group to the para and ortho positions, the chief product of the reaction being *p*-nitrobrombenzene (m.p. 126°). On the other hand, when nitrobenzene is brominated, the negative nitro group sends the halogen atom to the meta position, and an excellent yield of *m*-nitrobrombenzene (m.p. 56°) is formed.

The chemical properties of the three isomers illustrate the effect of the relative position of substituents on their activity. *o*-Nitrobrombenzene (m.p. 43°) is converted into *o*-nitroaniline when heated at 190° with an alcoholic solution of ammonia, and into *o*-bromphenol when heated at a high temperature with water and potassium hydroxide. In one reaction the halogen atom is removed by ammonia, and in the other the nitro group by potassium hydroxide. *p*-Nitrobrombenzene enters into similar reactions, but the meta compound is not affected by the same reagents under the same conditions. In general, the effect of a substituent on the activity of an atom or group decreases as we pass from the ortho to the para to the meta compound, the effect of the group in the meta position being much less than that of one in the other positions. The reactions of the three dinitrobenzenes, which have been described in section **385**, furnish an interesting example of this principle.

The compounds formed by nitrating the isomeric nitrobrombenzenes furnish an illustration of the principle in regard to the orienting effect of substituents on entering groups. The structures of the products formed are shown by the following formulas: —



In *o*-nitrobrombenzene there is one position which is para to bromine and meta to the nitro group; this position is accordingly taken by an entering group. In *p*-nitrobrombenzene the most favorable position is the one ortho to bromine and meta to the nitro group. There is no position in *m*-nitrobrombenzene to which both bromine and the nitro group tend to send a substituent, and, as a consequence, a mixture of compounds is obtained, among which the substance of the structure given above is present in the largest amount. In the formation of this compound the directing influence of the bromine atom predominates, and the substituent takes its place para to the halogen, although this place is ortho to a nitro group.

KETONE-ALCOHOLS

497. Benzoin, $C_6H_5.CO.CHOH.C_6H_5$, is an example of a ketone-alcohol. The method by which it is prepared from benzoic aldehyde has been given in section **481**. The oxygen atom and hydroxyl group, which give to benzoin its characteristic properties, are linked to carbon atoms not situated in a ring. As a consequence, benzoin resembles the analogous aliphatic compounds in many of its properties. Benzoin is an α-hydroxyketone as it contains the group – CO.CHOH –. It will be recalled that certain sugars, the ketoses, contain this group; like these, benzoin reduces Fehling's solution and forms a phenylhydrazone and an osazone.

Benzoin is oxidized by nitric acid to benzil, $C_6H_5.CO.CO.C_6H_5$. It is reduced by zinc and hydrochloric acid in alcoholic solution to desoxybenzoin, $C_6H_5.CO.CH_2.C_6H_5$, by sodium amalgam to hydrobenzoin, $C_6H_5.CHOH.CHOH.C_6H_5$, and by hydriodic acid to dibenzyl, $C_6H_5.CH_2.CH_2.C_6H_5$.

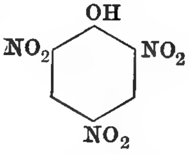
Derivatives of Phenols

498. Nitrophenols, $NO_2.C_6H_4.OH$. — *o*-Nitrophenol (m.p. 45°) and *p*-nitrophenol (m.p. 114°) are formed by the nitration of phenol. As the presence of the hydroxyl group facilitates markedly the introduction of substituents, the nitration is effected by dilute nitric acid at a low temperature. When reaction is complete the product is washed with water and distilled with steam, with which the ortho compound is volatile.

m-Nitrophenol (m.p. 96°) is prepared from *m*-nitroaniline by the diazo reaction. Many meta compounds are prepared from the dinitro-derivatives which result from direct nitration.

The nitrophenols are more acidic than phenols, as they decompose hot solutions of sodium carbonate. They are precipitated, however, from their solutions in alkalies by carbon dioxide.

499. Picric Acid, $(NO_2)_3.C_6H_2.OH$, trinitrophenol, has the symmetrical structure: —



It is formed as the result of the action of concentrated nitric acid on a large number of substances, such as certain proteins, resins, and many aromatic compounds. Picric acid is prepared by adding concentrated nitric acid to a solution of phenol in concentrated sulphuric acid, and finally heating the mixture at 100°.

Picric acid crystallizes from water in light yellow leaflets, and from ether in prisms; it has a bitter taste, is poisonous, and decomposes with explosion when heated rapidly. Aqueous solutions of picric acid have a distinctly yellow color; they dye silk and wool.

The salts of picric acid are used in explosives, as they decompose with great violence when struck or heated; the lead salt and the ammonium salt are of particular value for this purpose. *Lyddite* and *melinite* are said to contain picrates.

Picric acid exhibits acidic properties; it decomposes carbonates, and forms well characterized salts. The effect of the nitro groups in increasing the negative nature of the phenyl radical, is clearly seen in picric acid and its derivatives. The trinitrophenyl radical, $(NO_2)_3C_6H_2—$, is strongly negative; the compound formed by its union with hydroxyl is an acid, and that formed by its union with halogen $(NO_2)_3C_6H_2.Cl$, possesses the properties of an acyl chloride, although the halogen atom is joined to a carbon atom in a benzene ring. Trinitrochlorbenzene reacts with water and with ammonia according to the following equations: —

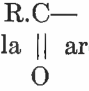
$$(NO_2)_3C_6H_2.Cl + HOH = (NO_2)_3C_6H_2.OH + HCl$$
$$(NO_2)_3C_6H_2.Cl + HNH_2 = (NO_2)_3C_6H_2.NH_2 + HCl$$

The analogy between the trinitrophenyl radical and acyl radicals is seen by comparing the properties of trinitroaniline and of acid amides. The amine may be prepared from the chloride according to the reaction expressed by the above equation, which is analogous to that made use of in the preparation of amides, or by the action of ammonia on the ethers of picric acid:

$$(NO_2)_3C_6H_2OCH_3 + NH_3 = (NO_2)_3C_6H_2NH_2 + CH_3OH$$

The method of preparation last given is similar to that by which amides are prepared from esters. Trinitroaniline, which is called picramide, reacts as an amide when heated with alkalies: —

$$(NO_2)_3C_6H_2.NH_2 + KOH = (NO_2)_3C_6H_2.OK + NH_3$$

All the reactions which have been given, bring out the important fact that a carboxyl group is not essential to an organic acid. The compounds which contain this group are acids because radicals of the general formula  $R.\underset{\underset{O}{\|}}{C}—$ are rendered negative by the presence of the oxygen atom. Any strongly negative radical yields an acid — a substance which gives hydrogen ions on solution in water — when it is linked to the hydroxyl group. The extent of ionization, and, consequently, the strength of the acid, is determined by the extent to which the negative nature of the radical in combination with hydroxyl is developed. Picric acid is a stronger acid than acetic acid, although the latter contains a carboxyl group and the former does not.

Picric acid forms with a number of aromatic hydrocarbons molecular compounds which crystallize well, can be readily purified, and possess definite melting-points. Such compounds are frequently prepared in the isolation of hydrocarbons and in their identification. The molecular compounds are decomposed into their constituents when treated with ammonia.

500. Bromphenols, $Br.C_6H_4.OH$. — The presence of the hydroxyl group in phenol makes the replacement of hydrogen atoms by halogen take place so readily that special precautions have to be taken in order to replace but one hydrogen atom. When a current of air which contains bromine vapor is passed into phenol, a mixture of *o*-bromphenol (b.p. 185°) and *p*-bromphenol (m.p. 64°) is formed. The compounds are best prepared from the corresponding bromanilines by the diazo-reaction. This reaction is used in preparing *m*-bromphenol (m.p. 33°), as a halogen atom does not enter the ring meta to a hydroxyl group, if there is a hydrogen atom in the ring ortho or para to this group.

When an aqueous solution of phenol is treated with bromine-water, symmetrical tribromphenol (m.p. 95°) is formed; in the presence of an excess of bromine-water an unstable compound of the formula $Br_3C_6H_2.OBr$ is precipitated.

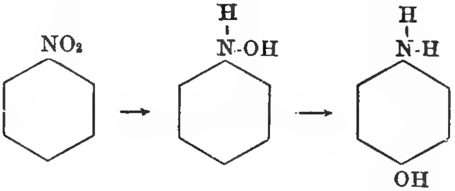
501. Phenolsulphonic Acids, $HO.C_6H_4.SO_3H$. — When phenol is treated in the cold with concentrated sulphuric acid, the chief product of the reaction is the ortho acid. In many cases a low temperature favors the formation of ortho compounds. When the sulphonation is effected by warming phenol with sulphuric acid, the para compound is formed. The ortho acid rearranges into the para acid when it is boiled with water.

m-Phenolsulphonic acid is prepared by the cautious fusion of *m*-benzenedisulphonic acid with potassium hydroxide; with an excess of alkali and at a higher temperature, resorcinol is formed.

The chemical properties of the phenolsulphonic acids are those of sulphonic acids and phenols. When heated with water and hydrochloric acid under pressure, they are converted into phenol, and when fused with alkalies, dihydroxybenzenes are formed. Like phenols, they react readily with halogens. Bromine-water converts *p*-phenolsulphonic acid into mono- and disubstitution-products, and finally into tribromphenol.

The mixture of *o*- and *p*-phenolsulphonic acids formed by sulphonating phenol, is used as a disinfectant under the name *aseptol;* the sodium salts of the acids are used as a remedy for the form of indigestion which results from a certain kind of fermentation in the stomach.

502. Aminophenols, $NH_2.C_6H_4.OH$. — The three aminophenols may be prepared by reducing the three nitrophenols. *p*-Aminophenol (m.p. 170°) is manufactured by the electrolytic reduction of nitrobenzene dissolved in sulphuric acid. Phenylhydroxylamine is first formed, and then undergoes rearrangement in the presence of the strong acid into *p*-aminophenol: —



The rearrangement is similar to those which take place in the cases of nitrosomethylaniline and diazoaminobenzene, which have been mentioned (**420**, **430**).

The aminophenols possess the properties of amines and of phenols, although the mutual effect of the groups modifies to some extent their activity. The influence of the positive amino group is seen in the fact that the compounds do not form well characterized salts with bases, although they are soluble in alkalies. Like aniline, they form salts with active acids, and yield diazo compounds.

The aminophenols are colorless, crystalline solids, which readily turn brown in the air as the result of oxidation. Their salts are more stable.

503. The hydrochloride of *p*-aminophenol is used as a photographic developer under the name *rodinal.* A large number of organic compounds which are reducing agents have been used as photographic developers. A study of the structure of the aromatic compounds which give satisfactory results as developers, has led to the conclusion that such compounds contain at least two hydroxyl groups, two amino groups, or one hydroxyl and one amino group, in the ortho or para positions to each other. In the case of the amino groups, one of the hydrogen atoms may be replaced by an alkyl radical. In addition to pyrogallol (pyro) $C_6H_3(OH)_3(1, 2, 3)$, quinol (hydroquinone) $C_6H_4(OH)_2(1, 4)$, pyrocatechol (pyrocatechin) $C_6H_4(OH)_2(1, 2)$, and *p*-aminophenol, which have been mentioned, the following named substances are among those which have been used: *amidol,* which is a salt of diaminophenol (OH, 1; NH_2, 2; NH_2, 4), *metol,* the sulphate of methylaminocresol, (OH, 1; CH_3, 3; $NHCH_3$, 4), and *eikonogen,* which is a sulphonic acid of an aminonaphthol (NH_2, 1; OH, 2; SO_3H, 6).

A number of derivatives of *p*-aminophenol are used in medicine. The ethyl ether of the phenol, $H_2N.C_6H_4.OC_2H_5$, is known as *paraphenetidin,* from which compounds have been prepared by replacing a hydrogen atom of the amino group by acyl radicals. *Phenacetin,* which is used as an antipyretic, is the acetyl derivative and has the formula, $CH_3CO.HN.C_6H_4.OC_2H_5$.

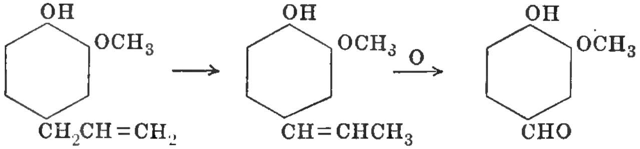
504. **Guaiacol**, $CH_3O.C_6H_4.OH(1, 2)$, is so-called because it was first obtained from gum guaiacum. It is found among the products of the distillation of wood, and can be prepared from pyrocatechol, of which it is the monomethyl ether. It melts at 28.5° and boils at 205°.

Guaiacol possesses the properties of a phenol and of an ether. It dissolves in alkalies, gives a green coloration with ferric chloride, and is converted into anisol, $C_6H_5OCH_3$, when heated with zinc-dust.

505. **Eugenol**, $C_6H_3(OH)(OCH_3)(CH_2CH=CH_2)(1, 2, 4)$, occurs in a number of essential oils. Oil of cloves consists of eugenol and a terpene of the formula $C_{15}H_{24}$. The oil may be obtained by distilling cloves with steam. Eugenol is a colorless oil with a spicy odor, which boils at 247°. It may be separated from the oil of cloves by treating the latter with an alkali; the phenol dissolves, whereas the hydrocarbon is insoluble. On the addition of acid to the alkaline solution, eugenol is precipitated.

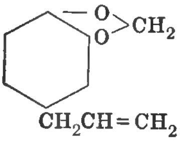
Eugenol possesses the properties of phenols, unsaturated compounds, and ethers. Ferric chloride colors its ammoniacal solution blue, and acetic anhydride converts it into an acetyl derivative. Bromine forms with it dibromeugenol-dibromide, the substitution being brought about as the result of the presence of the phenolic hydroxyl group, and the addition as the result of the presence of the double bond.

When eugenol is boiled with an alcoholic solution of potassium hydroxide, it is converted into isoeugenol; both compounds yield vanillin on oxidation with potassium permanganate: —



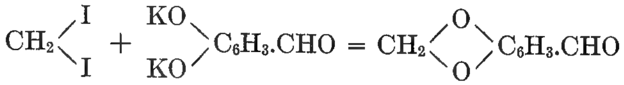
A number of derivatives of eugenol are used as medicinal preparations.

506. Safrol is a methylene ether of the structure, —



It is the chief constituent of the oil of sassafras, and is present in other essential oils. It does not possess phenolic properties. It is converted by alkalies into isosafrol, a change taking place similar to that which eugenol undergoes with the same reagent. Safrol is oxidized in acid solution to acetic aldehyde and piperonal, $CH_2.O_2:C_6H_3.CHO$, and in alkaline solution to piperonylic acid, $CH_2.O_2:C_6H_3.COOH$.

Piperonal possesses the odor of heliotrope, and is used in perfumery. It may be prepared by treating an alkaline solution of protocatechuic aldehyde with methylene iodide: —



$$\mathrm{CH_2}\begin{matrix}\diagup \mathrm{I}\\ \diagdown \mathrm{I}\end{matrix} + \begin{matrix}\mathrm{KO}\diagdown\\ \mathrm{KO}\diagup\end{matrix}\mathrm{C_6H_3.CHO} = \mathrm{CH_2}\begin{matrix}\diagup \mathrm{O} \diagdown\\ \diagdown \mathrm{O} \diagup\end{matrix}\mathrm{C_6H_3.CHO}$$

HYDROXY-ALDEHYDES

507. Hydroxyl derivatives of aldehydes are usually prepared by what is known as the Tiemann-Reimer reaction, which consists in condensing a phenol with chloroform in the presence of an alkali. It is probable that the reaction takes place in steps as indicated by the following equations: —

$$\mathrm{KO.C_6H_4}\boxed{\mathrm{H + Cl}}\mathrm{CHCl_2 + KOH = KO.C_6H_4.CHCl_2 + KCl + H_2O}$$

$$\mathrm{KO.C_6H_4.CH}\boxed{\mathrm{Cl_2 + H_2}}\mathrm{O = KO.C_6H_4.CHO + 2HCl}$$

The condensation is effected by adding chloroform to a warm solution of phenol in an excess of potassium hydroxide. In the first reaction represented above, a hydrogen atom of the benzene ring is replaced by the group $CHCl_2$ as the result of the elimination of hydrochloric acid. The hydrogen atoms which enter into reaction are those in the positions ortho and para to the hydroxyl group. When phenol is used, a mixture of *o*-hydroxy- and *p*-hydroxybenzaldehyde is obtained. As in other cases, the hydroxyl group sends the entering group to the ortho and para positions. The second step in the formation of the aldehyde is similar to the reaction by which benzal chloride is converted into benzaldehyde.

508. Salicylic Aldehyde, $HO.C_6H_4.CHO(1, 2)$, occurs in the oil of spiroea, which is obtained from the blossoms of the meadow-sweet. It is prepared from phenol by the Tiemann-Reimer reaction. Salicylic aldehyde is a liquid with a pleasant odor, which is volatile with steam and boils at 196.5°. It shows the properties of a phenol and an aldehyde; it gives a violet coloration with ferric chloride, and forms an addition-product with potassium hydrogen sulphite, but does not reduce Fehling's solution.

Salicylic aldehyde can be oxidized to *o*-hydroxybenzoic acid and reduced to *o*-hydroxybenzyl alcohol. As a phenol it yields ethers and esters, and as an aldehyde, condensation-products.

509. Vanillin, $C_6H_3.OH.OCH_3.CHO$ (1, 2, 4), is the chief constituent of the extract of vanilla, which is obtained by treating vanilla beans with alcohol. It may be prepared from guaiacol by the Tiemann-Reimer reaction. It is made on the large scale by oxidizing isoeugenol — a reaction described above — and from coniferin, a glucoside which occurs in the sap of certain conifers. Coniferin is converted by hydrolysis into glucose and coniferyl alcohol, $C_6H_3(OH)(OCH_3)(C_3H_4OH)$(1, 2, 4); the latter yields vanillin on oxidation.

Vanillin crystallizes in needles which melt at 81°. It gives a blue coloration with an aqueous solution of ferric chloride, reduces an ammoniacal solution of silver nitrate, and decomposes carbonates. It is oxidized by moist air to vanillic acid, which is formed as the result of the conversion of the aldehyde group into a carboxyl group.

SUBSTITUTION-PRODUCTS OF AMINES

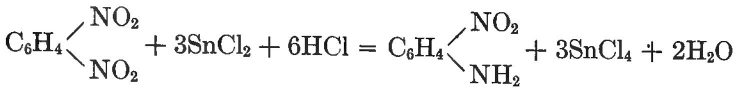
510. Sulphanilic Acid, $NH_2C_6H_4.SO_3H$(1, 4), *p*-aminobenzenesulphonic acid, is the most important sulphonic acid derived from aniline. It is prepared by heating a mixture of aniline and concentrated sulphuric acid for about 4 hours at 180°–190°.

Sulphanilic acid is difficultly soluble in cold water, and crystallizes from hot water in crystals which contain two molecules of water and effloresce quickly.

Sulphanilic acid, like other para compounds, is converted by chromic acid into quinone. With nitrous acid it yields a diazo compound, which is used in the preparation of valuable dyes. It forms well characterized salts with bases, but does not form salts with acids on account of the presence of the strongly negative sulphonic acid group which it contains.

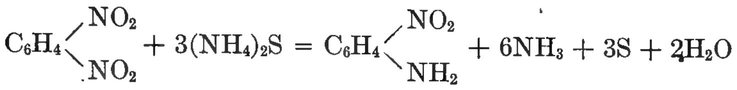
The isomers of sulphanilic acid which contain the amino and sulphonic acid groups in the ortho and meta positions, respectively, are prepared by reducing the corresponding nitrobenzenesulphonic acids.

511. Nitranilines, $NO_2.C_6H_4.NH_2$. — The most readily prepared nitraniline (or nitroaniline) is that which is formed by the partial reduction of *m*-dinitrobenzene. This is accomplished by treating a cold alcoholic solution of the dinitrobenzene with the calculated quantity of a solution of stannous chloride and hydrogen chloride in alcohol: —



$$C_6H_4\begin{array}{l}\diagup NO_2\\ \diagdown NO_2\end{array} + 3SnCl_2 + 6HCl = C_6H_4\begin{array}{l}\diagup NO_2\\ \diagdown NH_2\end{array} + 3SnCl_4 + 2H_2O$$

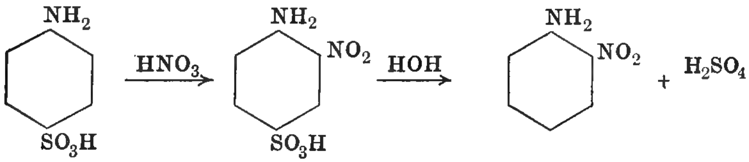
The reduction can be effected also by heating the nitro compound with an alcoholic solution of ammonium sulphide: —



$$C_6H_4\begin{array}{l}\diagup NO_2\\ \diagdown NO_2\end{array} + 3(NH_4)_2S = C_6H_4\begin{array}{l}\diagup NO_2\\ \diagdown NH_2\end{array} + 6NH_3 + 3S + 2H_2O$$

o-Nitraniline and *p*-nitraniline are prepared by methods which illustrate the way in which compounds are formed which cannot be made by direct substitution. When aniline is treated with concentrated nitric acid, it is difficult to control the reaction so as to form a mono-nitro compound. In order to decrease the activity of aniline, the amino group is modified by introducing into it a radical which can be readily removed after substitution has taken place; the acetyl group is commonly employed for this purpose. When acetanilide is nitrated a mixture of *p*- and *o*-nitroacetanilide is formed, from which the nitranilines may be obtained by hydrolysis. When a solution of aniline in a large excess of concentrated sulphuric acid is treated with nitric acid, a mixture of *m*- and *p*-nitraniline is formed.

Orthonitraniline and *p*-nitraniline may be obtained in pure condition by methods which are frequently applied in the preparation of other compounds. The ortho compound may be prepared by heating *o*-nitrophenol with ammonia at 160° for 16 hours, and by the reactions indicated by the following formulas: —



The amino group sends an entering group to the para position. In order to prevent the nitro group from taking this position, aniline is first sulphonated. When the resulting compound or its acetyl derivative is nitrated, the nitro group enters the ring ortho to amino and meta to the negative acid group. The nitro-aminosulphonic acid is then heated with water and hydrochloric acid under pressure, when the sulphonic acid group is replaced by hydrogen. *p*-Nitraniline can be made by heating *p*-chlornitrobenzene or *p*-nitrophenol with ammonia under pressure. It is usually prepared by nitrating acetanilide, and saponifying the resulting nitroacetanilide.

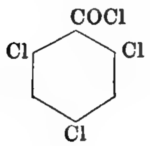
The nitranilines are weak bases; they are difficultly soluble in water, and form salts which are decomposed by water. The ortho, meta, and para compounds melt at 71°, 114°, and 147°, respectively.

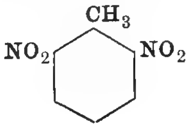
SUBSTITUTION-PRODUCTS OF ACIDS

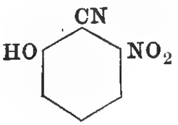
512. Nitrobenzoic Acids, $NO_2.C_6H_4.COOH$. — When benzoic acid is heated with concentrated nitric acid, *m*-nitrobenzoic acid is formed. As nitration takes place with difficulty, the acid is usually prepared by treating a mixture of benzoic acid and potassium nitrate with concentrated sulphuric acid. When nitration is effected in this way, the presence of the water contained in concentrated nitric acid is avoided, and a more active nitrating mixture is, consequently, obtained. The difficulty with which a nitro group is introduced into benzoic acid, is met with in the case of other compounds containing strongly negative substituents. The product of the nitration effected in the way just described is a mixture of the meta, ortho, and para acids, in the proportion of about 60, 17, and 2 per cent, respectively, the rest being unaltered benzoic acid. The acids are separated by means of their barium salts, which differ in solubility in water. Isomeric acids are frequently separated by the fractional crystallization of their salts.

o-Nitrobenzoic acid is prepared by oxidizing *o*-nitrotoluene or *o*-nitrocinnamic acid, which is formed by the direct nitration of cinnamic acid. *p*-Nitrobenzoic acid is usually prepared by oxidizing *p*-nitrotoluene or *p*-nitrobenzyl chloride. The ortho, meta, and para acids melt at 147°, 142°, and 240°, respectively; the amides of the acids melt at 176°, 142°, and 198°, respectively.

513. Dinitrobenzoic Acids, $(NO_2)_2.C_6H_3.COOH$. — The most interesting of these acids is the one which contains the two nitro groups in the positions ortho to the carboxyl group. It has been pointed out in the case of picric acid and other compounds that the reactivity of an atom or group is greatly increased by the presence in the compound of substituents in the ortho position to the atom or group. It is possible, for example, to replace readily a chlorine atom situated between two nitro groups by the hydroxyl, methoxyl, amino, and other groups. In the light of these facts the influence on the carboxyl group of two groups in the ortho position to it, is of interest. The carboxyl group can be replaced more or less readily by other groups; for example, 2, 6, 1-dinitrobenzoic acid is converted into *m*-dinitrobenzene when heated, and into *m*-diaminobenzene when reduced with tin and hydrochloric acid. When, however, an attempt is made to convert the acid into an ester, the replacement of hydrogen by alkyl takes place with great difficulty. Most aromatic acids are converted into esters when a solution of the acid in alcohol is saturated with hydrogen chloride. Victor Meyer studied the esterification of many acids in this way, and came to the conclusion that acids which contain a carboxyl group placed between two radicals in the ortho position to this group, do not yield esters when treated in the way indicated above. This conclusion is known as *Victor Meyer's law of esterification.* Esters of such acids can be prepared, however, by the action of alkyl iodides on the silver salts of the acids. It is a striking fact that esters of this type can be saponified only slowly and by the most active reagents. In general, it has been found very difficult to effect transformations in groups which are protected on either side by other groups; for example, the compounds of the formulas,



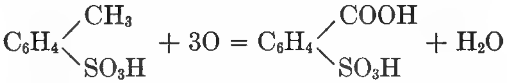




do not exhibit the properties characteristic of substances of the classes to which they belong. The acid chloride can be boiled for a long time with water without change; the hydrogen atoms in the methyl group of the dinitrotoluene are not replaced by chlorine when the compound is treated with the halogen at 200°; and the nitrile can not be hydrolyzed to the corresponding acid.

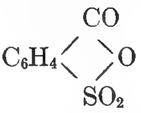
The explanation put forward by Meyer of such facts as these was based on what is called steric hindrance. It was thought that the groups in the ortho position prevented by their presence other molecules from coming into contact with the group between them, and, as a consequence, reaction could not take place. Recent work has shown, however, that the diortho acids form esters normally, but that the rate of the reaction is exceedingly slow. It is doubtful whether steric hindrance is the cause of the marked inactivity of the compounds which have been mentioned.

514. Sulphobenzoic Acids, $HO_3S.C_6H_4.COOH$. — *m*-Sulphobenzoic acid is obtained by the direct sulphonation of benzoic acid with sulphur trioxide. The ortho and para acids are prepared by oxidizing the corresponding toluenesulphonic acids: —

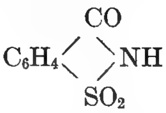


$$C_6H_4\left\langle\begin{matrix}CH_3\\SO_3H\end{matrix}\right. + 3O = C_6H_4\left\langle\begin{matrix}COOH\\SO_3H\end{matrix}\right. + H_2O$$

Like phthalic acid, $C_6H_4(COOH)_2$, *o*-sulphobenzoic acid yields an anhydride and an imide: —



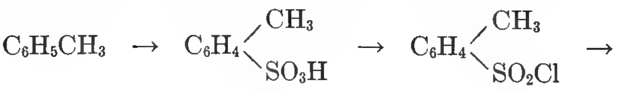
$$C_6H_4\left\langle\begin{matrix}CO\\SO_2\end{matrix}\right\rangle O$$



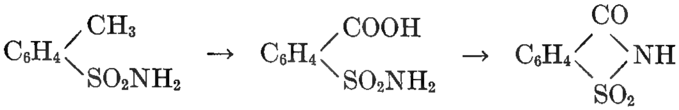
$$C_6H_4\left\langle\begin{matrix}CO\\SO_2\end{matrix}\right\rangle NH$$

The imide is of particular interest on account of the fact that it possesses a taste which is about 500 times as sweet as that of cane sugar; it is called *saccharin.*

Saccharin can be prepared from toluene by the transformations indicated by the following formulas: —



$$C_6H_5CH_3 \rightarrow C_6H_4\left\langle\begin{matrix}CH_3\\SO_3H\end{matrix}\right. \rightarrow C_6H_4\left\langle\begin{matrix}CH_3\\SO_2Cl\end{matrix}\right. \rightarrow$$



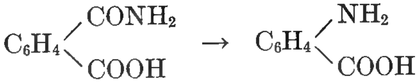
The product of sulphonation of toluene is a mixture of *p*- and *o*-toluenesulphonic acids. The acids are converted into the sulphonyl chlorides, which may be separated, as the para compound is a solid and the ortho compound is a liquid. The liquid chloride is next converted by ammonia into the amide, which is oxidized in aqueous solution with potassium permanganate. On acidifying the solution saccharin is obtained.

Saccharin (m.p. 220°) is manufactured on the large scale. It is used for sweetening purposes, as a preservative, and as a substitute for sugar by persons suffering from diabetes.

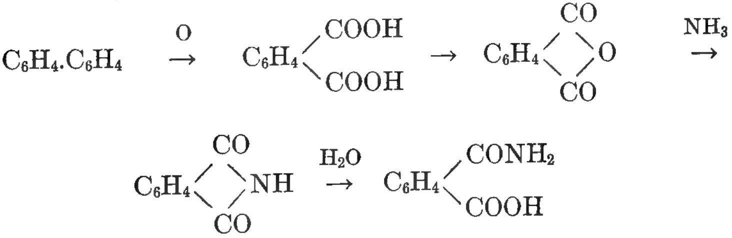
515. Aminobenzoic Acids, $NH_2.C_6H_4.COOH$. — The most important of the aminobenzoic acids is the ortho compound, which is called anthranilic acid. It was first obtained from indigo (*anil*). It is manufactured on the large scale in the synthetic preparation of indigo by a method which is an application of Hofmann's reaction for the preparation of amines. It will be recalled that acetamide is converted by a solution of bromine in sodium hydroxide into methylamine: —

$$CH_3.CONH_2 \rightarrow CH_3.NH_2$$

In a similar way phthalamidic acid is converted by bleaching-powder into anthranilic acid: —



Phthalamidic acid is prepared from naphthalene by the reactions indicated by the following formulas: —



In practise, phthalimide is treated with bleaching-powder, as it is not necessary to isolate the phthalamidic acid formed in the reaction.

Anthranilic acid melts at 145°, and can be sublimed without decomposition. It possesses a sweet taste, is readily soluble in water, and forms salts with acids and with bases. Esters of anthranilic acid have a pleasant odor, and are used in perfumery.

m-Aminobenzoic acid (m.p. 174°) is prepared by reducing *m*-nitrobenzoic acid. The para acid (m.p. 186°) is prepared by oxidizing the acetyl derivative of *p*-toluidine, and hydrolyzing the resulting compound: —

$$CH_3CO.NH.C_6H_4.CH_3 \rightarrow CH_3CO.NH.C_6H_4COOH \rightarrow NH_2.C_6H_4.COOH + CH_3COOH$$

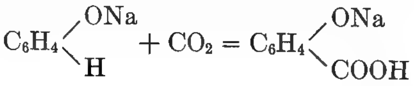
The free amine cannot be converted directly into the acid, as oxidizing agents destroy the amino group; in general, such groups are "protected" when a compound containing them is to be oxidized.

HYDROXY-ACIDS

516. Salicylic Acid, $HO.C_6H_4.COOH(1, 2)$, is the most important hydroxybenzoic acid. It derives its name from salicin, a glucoside obtained from the bark of the willow (*salix*), which yields glucose and *o*-hydroxybenzyl alcohol on hydrolysis.

Salicylic acid occurs in the blossoms of the meadow-sweet, in the leaves and stems of tulips and hyacinths, and as the methyl ester in the oil of wintergreen. The acid crystallizes in colorless needles from hot water, melts at 156°, and sublimes at 200° when carefully heated.

Salicylic acid can be prepared by the oxidation of *o*-hydroxybenzyl alcohol, by the fusion of *o*-toluenesulphonic acid and other ortho acids with potassium hydroxide, by heating with water the diazo compound formed from anthranilic acid, and in other ways. It is manufactured by what is known as Kolbe's synthesis, which consists in heating the sodium salt of phenol with carbon dioxide under pressure at 130°: —



$$C_6H_4\begin{cases}ONa\\H\end{cases} + CO_2 = C_6H_4\begin{cases}ONa\\COOH\end{cases}$$

The compound formed yields salicylic acid when treated with an acid.

Salicylic acid possesses the properties of a phenol and an acid. It gives a violet coloration with ferric chloride, a precipitate with bromine-water ($C_6H_2Br_3.OBr$), and salts with bases. It forms ethers and esters such as those of the formulas —

$$C_6H_4.OCH_3.COOH,\ C_6H_4.OH.COOCH_3,\ C_6H_4.OCH_3.COOCH_3,\ \text{and}\ C_6H_4(O.COCH_3)COOH.$$

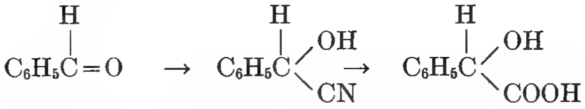
Salicylic acid is a powerful antiseptic, and is used in the preservation of food, wines, and beer; its sodium salt is employed as a remedy in the treatment of rheumatism. Phenyl salicylate, $C_6H_4.OH.COOC_6H_5$, called *salol,* is used in medicine for internal antisepsis; in the intestine it undergoes hydrolysis to phenol and salicylic acid. A great many remedies are derived from salicylic acid: *aspirin* is the acetyl derivative of salicylic acid, $C_6H_4(O.COCH_3)COOH$, and *betol,* is the β-naphthol ester of the acid.

517. ***m*-Hydroxybenzoic Acid**, $HO.C_6H_4.COOH(1, 3)$, may be prepared from *m*-aminobenzoic acid by the diazo reaction, and by fusing meta compounds such as *m*-sulphobenzoic acid, *m*-cresol, and *m*-chlorobenzoic acid with potassium hydroxide. *m*-Hydroxybenzoic acid crystallizes from hot water, and melts at 200°; its solutions are not colored by ferric chloride.

518. ***p*-Hydroxybenzoic Acid**, $HO.C_6H_4.COOH(1, 4)$, is formed in reactions which are analogous to those used to prepare the meta acid. It may be prepared by the action of carbon dioxide on potassium phenolate at 200°. When potassium salicylate is heated at 220°, it is converted into the salt of *p*-hydroxybenzoic acid of the formula $C_6H_4OK.COOK$; sodium salicylate does not undergo this change.

p-Hydroxybenzoic acid melts at 213°, and at 220° decomposes into phenol and carbon dioxide. With an aqueous solution of the acid, ferric chloride forms a yellow amorphous precipitate; bromine-water gives tribromphenol and carbon dioxide.

519. **Mandelic Acid**, $C_6H_5.CHOH.COOH$. — This compound is an example of acids which contain a hydroxyl group in the side-chain. It is made by the general method used to prepare α-hydroxy-acids. When benzaldehyde is treated with potassium cyanide and hydrochloric acid, the hydrocyanic acid formed unites with the aldehyde to form a nitrile, which yields mandelic acid on hydrolysis: —



Mandelic acid crystallizes from water in rhombic crystals, which melt at 118°. The acid contains an asymmetric carbon atom; the inactive synthetic variety can be converted into dextro- and levo-rotatory acids by crystallizing its cinchonine salt, or by the action of certain bacteria.

The structure assigned to mandelic acid is in accord with its reactions. It is oxidized by an alkaline solution of potassium permanganate in the cold to phenylglyoxylic acid: —

$$C_6H_5.CHOH.COOH + O = C_6H_5.CO.COOH + H_2O$$

Fuming hydrobromic acid converts it into α-bromphenylacetic acid, $C_6H_5.CHBr.COOH$, and hydriodic acid and red phosphorus into phenylacetic acid, $C_6H_5.CH_2.COOH$. The acid cannot be nitrated, as concentrated nitric acid oxidizes it to benzaldehyde.

As an alcohol, mandelic acid forms compounds of the type $C_6H_5.CH(OCH_3)COOH$ and $C_6H_5.CH(O.OCCH_3).COOH$ and as an acid those of the type $C_6H_5.CHOH.COOCH_3$. The reactions of these compounds are what might be expected from their formulas.

520. Tyrosine, $HO.C_6H_4.CH_2.CHNH_2.COOH$, which is α-animo-β-*p*-hydroxyphenylpropionic acid, is an important product of the hydrolysis of many proteins. The acid has been synthesized from β-phenylpropionic acid, $C_6H_5.CH_2.CH_2.COOH$, which can be prepared from benzyl chloride by the use of the malonic ester synthesis. The first steps in the synthesis are indicated by the following formulas:

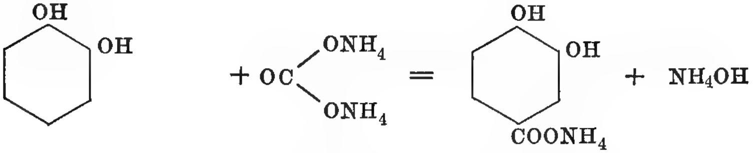
$$C_6H_5.CH_2.CH_2.COOH \xrightarrow{HNO_3} NO_2.C_6H_4.CH_2.CH_2.COOH \xrightarrow{Br}$$

$$NO_2C_6H_4.CH_2.CHBr.COOH \xrightarrow{NH_3}$$
$$NO_2.C_6H_4.CH_2.CHNH_2.COOH$$

The nitro group in the acid prepared in this way was replaced by a hydroxyl group through the diazo reaction.

Tyrosine has been prepared by a number of interesting methods; one of these involves the condensation of *p*-hydroxybenzaldehyde and hippuric acid, $C_6H_5CO.NH.CH_2COOH$, by a reaction similar to that which takes place in Perkin's synthesis.

521. Protocatechuic Acid, $(HO)_2C_6H_3.COOH(3,4,1)$, is obtained from many resins when they are fused with potassium hydroxide, and is a product of the hydrolysis of certain tannins, which will be described later. It can be prepared by fusing with an alkali a number of compounds which contain groups in the meta and para position to a carboxyl group. The preparation of the acid from pyrocatechol is of interest; it is formed when the phenol is heated with ammonium carbonate and water at 140°: —



Protocatechuic acid is soluble in water, and melts at 199°. Ferric chloride colors its aqueous solution bluish-green, the color changing to blue and finally to red on the addition of alkalies. The acid reduces an ammoniacal solution of silver nitrate, but does not reduce Fehling's solution. It decomposes into pyrocatechol and carbon dioxide when distilled. Bromine in the cold forms bromprotocatechuic acid; at 100° the carboxyl group is eliminated and tetrabrompyrocatechol is formed. The monomethyl ether, $C_6H_3(OH)(OCH_3)COOH(4, 3, 1)$, is called vanillic acid, as it is formed by the oxidation of vanillin. The dimethyl ether, *veratric acid*, and the methylene ether, $CH_2{:}O_2{:}C_6H_3COOH$, *piperonylic acid*, are obtained from a number of substances which occur in nature.

522. Gallic Acid, $C_6H_2(OH)_3COOH(3, 4, 5, 1)$, is the most important trihydroxybenzoic acid. It occurs in gall-nuts, sumach, acorns, tea, walnuts, and in the astringent parts of many plants. It is prepared by boiling tannin with dilute acids. The acid crystallizes with one molecule of water, which is given off at 100°–120°. It does not have a definite melting-point; at 215° it begins to decompose into pyrogallol and carbon dioxide. Gallic acid reduces Fehling's solution and the salts of silver and of gold; it gives with ferric chloride a bluish-black precipitate, which dissolves in an excess of the reagent to form a green solution.

523. Tannic Acids. — The name tannic acid or tannin is applied to a number of vegetable acids which are widely distributed in nature. Tannins occur in the bark of trees and in the leaves and roots of plants. The chief commercial sources of tannin are gall-nuts, sumach, oak and hemlock bark, and a number of plants and trees which grow in India and South America. Tannin is used in the tanning of leather and as a mordant in dyeing. The tannins differ in their reactions with other substances and the products which they yield on hydrolysis, but possess certain properties in common. The tannins are amorphous solids of astringent taste, which are more or less soluble in water and in alcohol, and do not melt or volatilize without decomposition. They give blue-black or green colorations with ferric chloride, and precipitates with lead acetate, copper acetate, and many organic compounds which yield salts with acids. The most characteristic property of tannins is their ability to form with gelatin or gelatin-forming tissues the insoluble compounds which constitute leather.

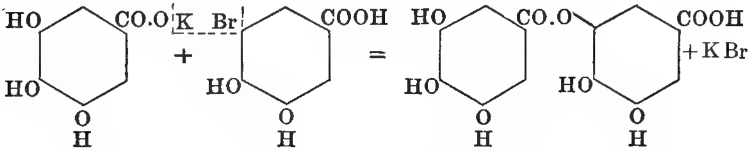
All tannins are active reducing agents; they reduce Fehling's solution and absorb oxygen from the air, — the reaction taking place rapidly in alkaline solutions, — and form colored oxidation-products.

The tannins may be divided into two classes. To one belong the tannins which give a blue-black coloration with ferric chloride, and yield gallic acid on hydrolysis and pyrogallol when decomposed by heat; the tannins of the second class give green solutions with ferric chloride and yield pyrocatechol when heated. The tannins of the first class are converted by fusion with caustic alkalies into gallic acid or ellagic acid, which is derived from the tannin by loss of water; the tannins of the second class yield under the same conditions protocatechuic acid, together with phloroglucinol and acetic acid or other fatty acid. These facts lead to the view that one class of tannins is derived from gallic acid, and the other is derived from protocatechuic acid.

524. Gallotannic Acid, digallic acid, $C_{14}H_{10}O_9$, is an example of the tannins derived from gallic acid. It occurs as a glucoside or in combination with other carbohydrates in gall-nuts, which contain about 70 per cent of the acid. Galls or gall-nuts is the name given to the excrescences on various kinds of trees which are formed as the result of the puncture of the bark by insects.

Gallotannic acid separated from gall-nuts by extraction with alcohol, ether, and water, is obtained as a colorless amorphous mass or light yellow scales. It is soluble in six parts of cold water, and is precipitated by dilute hydrochloric acid or sodium chloride. It is removed from its solutions by skin or other gelatinous material. At 215° it begins to decompose, and pyrogallol and carbon dioxide are formed. Gallotannic acid reduces the salts of silver, gold, mercury, and copper, and precipitates many alkaloids and proteins from their solutions.

Gallotannic acid has been synthesized by a method which furnishes evidence of its structure. It is formed by the action of the potassium salt of gallic acid on bromprotocatechuic acid:



The synthesis indicates that gallotannic acid is an ester derived from two molecules of gallic acid as the result of the interaction of the carboxyl group of one molecule with a hydroxyl group of the other. A synthesis of gallotannic acid from gallic acid confirms this view; it is formed when anhydrous gallic acid is heated with phosphorus oxychloride at 120°. The method of preparation in this case is that often used to prepare esters, namely, heating a mixture of an acid and an alcohol or phenol with phosphorus oxychloride; the phosphorus oxychloride converts the acid into an acid chloride which interacts with the hydroxyl derivative to form an ester.

The formula assigned to gallotannic acid is in accord with its reactions. The acid is converted into gallic acid by hydrolysis, forms a penta-acetyl derivative when heated with acetic anhydride, and is converted into the amide and the ammonium salt of gallic acid when boiled with a solution of ammonia. The structure of gallotanic acid may, however, be more complicated than that given, as the determination of its molecular weight indicates that the latter should be from two to four times that represented by the formula assigned to the acid.[1]

525. The tannin from gall-nuts is used in making *writing inks.* Ordinary inks were formerly made from an extract of galls to which a gum and ferrous sulphate were added. When such a mixture comes into contact with the air, the ferric salt formed produces a blue-black precipitate, which is held in suspension by the gum. Iron inks of this type may be removed from paper or fabrics by treating them with oxalic acid. The coloring matter of the ink — ferric gallotannate — is reduced by the acid to a ferrous salt, which is colorless and soluble in water.

Recently, writing inks have been made from organic dyes. Many of these cannot be decolorized by oxalic acid, as the reducing agent is not active enough to convert them into colorless compounds. Such inks are often destroyed when they are treated with solutions of sodium hypochlorite and hydrochloric acid.

Indelible inks consist of finely divided carbon held in suspension by gluten, an alkaline solution of shellac, or similar medium; they frequently contain indigo. Colored inks are usually solutions of coal-tar dyes to which gum arabic has been added in order to make the ink flow smoothly from the pen, and to prevent its spreading when put upon paper. Marking inks usually consist of a solution of the nitrate or other salt of silver to which some colored substance is added.

526. Caffetannic Acid, $C_{14}H_{16}O_7$, caffetannin, is an example of a tannin derived from protocatechuic acid. It occurs in coffee berries. When fused with potassium hydroxide, it yields protocatechuic acid and acetic acid, and when heated alone it gives pyrocatechol. It is not affected by a solution of gelatin.

The composition and structure of many tannins are not known with certainty. They are formed as the result of the elimination of water from gallic acid, protocatechuic acid, and perhaps other acids. On account of the number of hydroxyl groups which these acids contain, the possibilities of the formation of ethers, esters, anhydrides, and ketones by loss of water is great; and, as a consequence, many such compounds exist, of which the structure is unknown.

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[1] Recent work indicates that certain tannins are esters derived from glucose and gallic or digallic acid.

Ionization-Constants of Aromatic Acids

527. The nature of the substituents in an aromatic acid, and their position relative to the carboxyl group, have a marked effect upon the extent to which the acids are ionized in aqueous solution. A number of examples have been given of the effect of one group on the activity of another, and it has been pointed out that the positions of the groups with respect to each other, is an important factor in bringing about the difference in activity of isomeric compounds. The effect of a substituent on the activity of an acid, and the effect of the same substituent on the reactivity of compounds containing groups other than the carboxyl group, are probably traceable in part to the same cause, namely, the effect of the substituent in modifying the positive or negative nature of the radical in combination with the carboxyl or other groups present. One of the cases cited of the influence of groups on one another, was that of the dinitrobenzenes (**385**). One of the nitro groups of the ortho compound can be removed readily by certain reagents, whereas *m*-dinitrobenzene is not affected under the same conditions. In the light of this fact it is of interest to compare the effect of a nitro group in the ortho-position and one in the meta-position on the activity of a carboxyl group. The ionization constant of *o*-nitrobenzoic acid is 0.616, and that of *m*-nitrobenzoic acid is 0.035; an *o*-nitrophenyl radical is much more negative than a *m*-nitrophenyl radical. We should expect, therefore, a compound which contains the former to react with water more readily than one which contains the latter radical.

The conclusion as to the nature of a radical drawn from a consideration of the ionization-constant of the acid containing it, is a valuable guide in interpreting the chemical behavior of compounds which consist of the radical in combination with some atom or group. There appear to be, however, other factors, but little understood, which affect the influence of groups on one another, and, as a consequence, the conclusions arrived at in regard to the properties of certain compounds as the result of the study of the ionization-constants of acids, are not always strictly in accord with the facts.

The ionization-constants of a few aromatic acids are given below. The student will find it of interest to study the figures in connection with properties of the aromatic compounds which have been described, in the way exemplified above in the case of the dinitrobenzenes.

The effect of the relation of the position of a substituent to that of the carboxyl group is shown by the following constants: —

Acid	K	Acid	K
$C_6H_5.COOH$	.0060	$NO_2C_6H_4.COOH$(o)	.616
$ClC_6H_4.COOH$(o)	.132	$NO_2C_6H_4.COOH$(m)	.0354
$ClC_6H_4.COOH$(m)	.0155	$NO_2C_6H_4.COOH$(p)	.0396
$ClC_6H_4.COOH$(p)	.0093	$CH_3C_6H_4.COOH$(o)	.0120
$BrC_6H_4.COOH$(o)	.145	$CH_3C_6H_4.COOH$(m)	.00514
$BrC_6H_4.COOH$(m)	.0137	$CH_3C_6H_4.COOH$(p)	.00515
$HOC_6H_4.COOH$(o)	.102	$C_6H_5CH_2.COOH$	.00556
$HOC_6H_4.COOH$(m)	.0087	$C_6H_5CH_2CH_2.COOH$	.00227
$HOC_6H_4.COOH$(p)	.00286	$C_6H_5CH=CH.COOH$	.00355

A substituent in the position ortho to the carboxyl group has a marked effect on the ionization of the acid; the constant of *o*-nitrobenzoic acid is one hundred times that of benzoic acid. It is remarkable that even a positive group, like methyl, in the ortho position brings about an increase in the constant; the constant for *o*-toluic acid is twice that of benzoic acid. Such facts as this have not been explained.

The relation between the constant of the para acid and that of the ortho or meta acid varies with the nature of the substituent. While *p*-nitrobenzoic acid is a slightly stronger acid than *m*-nitrobenzoic acid, the constant of *p*-chlorbenzoic acid is only about one-half that of the meta acid. The case of *p*-hydroxybenzoic acid is a striking one; while *o*-hydroxybenzoic acid and *m*-hydroxybenzoic acid are more highly ionized than benzoic acid, the constant of the para acid is less than half that of benzoic acid. A satisfactory explanation of such facts as these would, no doubt, materially advance organic chemistry. The effect of a phenyl radical on a carboxyl group in a side-chain, is shown by the constants for phenylacetic acid, hydrocinnamic acid, and cinnamic acid.

The constants for a few of the acids which have been described in this chapter are given below. The carboxyl group in each case is numbered (1):

Acid	K	Acid	K
$NH_2.C_6H_4COOH$(2, 1)	.001	$(HO)_2.C_6H_3.COOH$(2, 6, 1)	5.00
$NH_2.C_6H_4.SO_3H$(4, 1)	.0581	$(HO)_3.C_6H_2.COOH$(3, 4, 5, 1)	.004
$(HO)_2.C_6H_3.COOH$(2, 3, 1)	.114	$C_6H_4.(COOH)_2$(2, 1)	.121
$(HO)_2.C_6H_3.COOH$(3, 4, 1)	.0033	$C_6H_4.(COOH)_2$(3,1)	.0287

PROBLEMS

1. Write equations for reactions by which the following may be prepared: (*a*) *m*-$C_6H_4.OH.COOH$, (*b*) *p*-$C_6H_4.OH.COOH$, (*c*) $C_6H_5.CHNH_2.COOH$ from $C_6H_5.CHO$, (*d*) $C_6H_3.CH_3(NO_2)_2$(1, 2, 4), (*e*) $C_6H_3(NO_2)_2COOH$ (4, 2, 1), (*f*) $C_6H_3(NO_2)_2COOH$(3, 5, 1), (*g*) $C_6H_3.SO_3H(COOH)_2$(5, 3, 1), (*h*) $C_6H_3.SO_3H$-$(COOH)_2$(4, 3, 1), (*i*) *p*-$C_6H_4.SO_3H.CH=CH.COOH$ starting with C_6H_5CHO, (*j*) *m*-$C_6H_4.SO_3H.CH=CH.COOH$ starting with C_6H_5CHO.

2. By what reactions could you convert (*a*) *p*-$C_6H_4.NH_2.OH$ into *p*-$C_6H_4(OH)_2$, (*b*) guaiacol into benzene, (*c*) *o*-$C_6H_4.OH.SO_3H$ into C_6H_6, (*d*) $C_6H_3.CH_3.NO_2.COOH$ (4, 3, 1) into $C_6H_5CH_3$, (*e*) C_6H_5OH into *p*-$C_6H_4.OH.$-CHO (*f*) *p*-$C_6H_4.CH_3.NO_2$ into *p*-$C_6H_4.CH_3.NHCOCH_3$?

3. Write equations for reactions by which tyrosine may be prepared from *p*-hydroxybenzoic aldehyde and hippuric acid.

4. Write the graphic formulas of the mono- and dibrom-substitution-products formed by the action of bromine on ortho, meta, and para aminobenzenesulphonic acids.

5. By what chemical tests could you distinguish from each other: (*a*) *m*-$C_6H_4.NO_2.Cl$ and $C_6H_2(NO_2)_3Cl$(2, 4, 6, 1), (*b*) $C_6H_5.CH_2NO_3$ and *p*-$C_6H_4.CH_3.NO_2$, (*c*) $C_6H_3.CH_3.Br.NO_2$(1, 2, 4) and *p*-$C_6H_4.CH_2Br.NO_2$, (*d*) *p*-$C_6H_4.CH_2OH.CH_3$ and *m*-$C_6H_4.OH.CH_3$, (*e*) *p*-$C_6H_4.NH_2.OCH_3$ and *p*-$C_6H_4.NH_2.OH$, (*f*) *p*-$C_6H_4.CH_3.COOH$, *p*-$C_6H_4.CH_3.OH$, and *p*-$C_6H_4.$-$CH_2OH.CH_3$, (*g*) *p*-$C_6H_4.CH_3.NH_2$ from *p*-$C_6H_4.CH_3.NHCH_3$, (*h*) $C_6H_2(NO_2)_3$-$COOH$ (2, 4, 6, 1) from $C_6H_2(NO_2)_3COOH$(3, 4, 5, 1)?

6. A compound of the composition C_7H_7Cl was converted by oxidation into *m*-chlorbenzoic acid. Write the graphic formula of the compound.

7. A compound of the composition $C_9H_{11}Cl$ was converted by mild oxidation into *p*-ethylbenzoic acid. Write the graphic formula of the compound.

8. A hydrocarbon of the formula $C_{13}H_{12}$ yielded the compound $C_{13}H_{10}O$ when oxidized, and the compound $C_{13}H_{10}N_2O_4$ when heated with nitric acid. Write a possible structural formula for the compound.

9. The substance $C_7H_6O_3$ was converted into the compound $C_8H_8O_3$ when warmed with methyl alcohol and concentrated sulphuric acid. When the original substance was treated with acetyl chloride the compound $C_9H_8O_4$. was obtained. Write a possible structural formula of the substance.

10. The hydrocarbon $C_{14}H_{14}$ was converted by oxidation into what proved to be *p*-benzoylbenzoic acid. Write the graphic formula of the compound, and indicate by equations how it could be prepared from toluene.

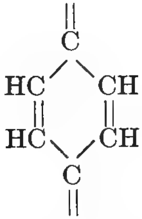
CHAPTER XXVIII

DYES

528. Dyes are compounds which can be used to color cotton, wool, linen, silk, leather, and other substances. In order to be of value as a dye the colored compound must unite with the substance to be dyed in such a way that the resulting product is not materially affected by the treatment to which it is subjected in use, such as rubbing or washing with soap and water. Dyes which are not appreciably affected by exposure to sunlight are said to be "fast"; those which fade rapidly are called "fugitive."

A study of the chemical composition of dyes and other colored compounds has led to certain important conclusions among which are the following: —

Every colored compound contains a particular grouping of atoms, called a "chromophore" group, to which the production of color can be attributed. Examples of the more important groups of this type are the nitro group, NO_2, azo group, $-N=N-$, and quinoid group,



The introduction into a colored compound of atoms or groups which do not of themselves produce color, such as bromine and alkyl groups, has a marked effect on the color. In general, an increase in molecular weight of a colored compound in this way is associated with a deepening of the shade, or a change in color which takes place ordinarily in the order yellow, orange, red, violet, blue, black.

Many colored compounds cannot be used as dyes on account of the fact that the color which they impart to wool or silk is readily removed by washing with water. In most cases, however, such compounds can be converted into dyes by introducing into them acidic or basic groups. Azobenzene, $C_6H_5N=NC_6H_5$, for example, is a bright-red compound, but does not possess the properties of a dye. The amino derivative of azobenzene, however, is a dye which is known as aniline yellow.

Some of the groups which impart to colored compounds the property of forming stable combinations with fabrics and thus convert them into dyes, have a marked effect in intensifying the color of the dye, while others have little effect. To the first class, which are called "auxochrome" groups, belong the hydroxyl, amino, and substituted amino groups. The sulphonic acid and carboxyl groups have little if any effect on the color of a compound into which they are introduced. Many dyes are converted into sulphonic acids, however, in order to render them more soluble in water.

The nature of the union between a dye and a fabric is still an open question. It is probable that in certain cases chemical compounds are formed, and that in others the fabric forms with the dye a solid solution, or holds it mechanically within its fibers. The fact that many colored substances which contain weakly acidic or basic groups dye wool and silk but do not dye cotton is evidence that the fixing of the dye in the animal fiber is probably the result of chemical action. Wool and silk are proteins and cotton is a carbohydrate. The proteins form compounds with weak acids and bases, whereas cotton, which is cellulose, reacts only with the strongest acids and bases. Cotton can be dyed by some organic compounds, however, — a fact which leads to the view that in certain cases the union of the dye and the fabric is of a physical nature.

Dyes may be classified according to their constitution, such as azo dyes, phthaleins, alizarines, etc., but from the standpoint of the dyer the more important classification is that which is based on the behavior of the dyes with fibers. Dyes are grouped in this way as substantive or direct, and adjective or mordant. In addition to the dyes belonging to these classes, there are a few, such as indigo, aniline black, and the so-called "ingrain colors," which are produced by chemical reactions within the fiber.

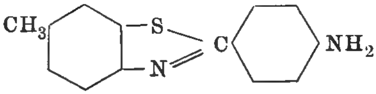
529. Substantive Dyes. — The dyes of this class are absorbed from solution by the fiber, and combine with it in such a way that the fiber is dyed by simply immersing it in the solution of the dye. With certain coloring matters dyeing is effected more readily in weakly acidic solution, and with others in weakly alkaline solution. Acid sodium sulphate, acetic acid, and tartaric acid are often added to the dye-bath. Silk is usually dyed in a weak soap-solution, or in a bath containing sodium phosphate. Salts are frequently added to the bath to reduce the solubility of the dye and to obtain faster or more even colors; sodium sulphate, sodium chloride, and magnesium sulphate are used for this purpose.

The animal fibers combine with most of the organic dyes. Cotton and other vegetable fibers cannot, in general, be dyed directly with the organic coloring matters except with certain so-called sulphur colors or with dyes derived from benzidine. Mercerized cotton, cellulose nitrates, and cellulose acetates can be dyed by substances which do not affect unaltered cellulose.

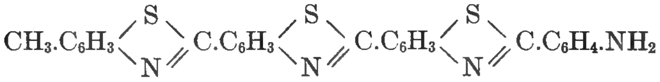
530. Adjective Dyes, Mordants. — The dyes classed as adjective are those which do not form stable combinations with fibers and, as a consequence, when they are used, the material to be dyed must be treated first with some substance with which the dye combines. Such substances are called mordants. The combination between the dye and the mordant may be physical or chemical. Finely divided substances, such as silica, sulphur, and calcium phosphate, absorb dyes readily, and serve as useful mordants in certain cases. Albumen is used in calico-printing, as it unites with substantive dyes directly. When cotton cloth which has been printed with a mixture of the dye and albumen is steamed, the protein is coagulated and the color becomes fixed.

The more widely applicable mordants are inorganic basic salts which form compounds with acidic dyes. When cotton is treated with aluminium acetate and subjected to the action of steam, the salt undergoes hydrolysis and basic acetates are formed. Cloth treated in this way can be dyed directly, as the basic salts form insoluble compounds with dyes. In mordanting cloth to be dyed with basic colors, a compound is used which is an acid or yields an acid on hydrolysis. Tannic acid, soap, and the so-called "pink salt," $SnCl_4.2NH_4Cl$, are examples of this class of mordants.

531. Ingrain Colors. — Dyes of this class are deposited on the fabric as the result of the formation of the color by a chemical reaction which takes place in the dye-bath. Primuline, which is used in the production of these dyes, is prepared by sulphonating the compound formed by heating *p*-toluidine with sulphur at about 250°. The first reaction which takes place leads to the formation of a compound which appears to have the structure,



By the further action of sulphur this compound is converted into one to which the following formula has been assigned: —



$$CH_3.C_6H_3\genfrac{<}{>}{0pt}{}{S}{N}C.C_6H_3\genfrac{<}{>}{0pt}{}{S}{N}C.C_6H_3\genfrac{<}{>}{0pt}{}{S}{N}C.C_6H_4.NH_2$$

The product is rendered soluble in water by converting it into a sulphonic acid. Primuline dyes cotton directly a lemon-yellow color. In order to deposit an ingrain color on cotton dyed with primuline, the cloth is first treated with a dilute acidified solution of sodium nitrite. Primuline, which contains an amino group, is thus converted into a diazonium salt. The material is next washed with cold water, and immersed in a solution of one of the naphthols, naphthylamines, or their derivatives. Azo compounds are formed in this way directly in the fabric, and, as a result, various shades of yellow, orange, scarlet, or maroon may be obtained. The ingrain colors are characterized by their extraordinary fastness to scouring and acids.

532. The commercial names given to dyes do not as a rule indicate their structure or the compounds from which they are prepared. Different manufacturers give different names to the same dye: Thus, dimethyl-amino-azobenzene-sulphonic acid is known in trade as methyl orange, helianthin, Poirrier's orange D, orange III, gold orange, and mandarin orange. The letters appended to the commercial names of dyestuffs are usually indicative of the shade, R referring to red (rot), G to yellow (gelb), and B to blue (blau); 2R, 3R, etc., indicate a deeper shade than that represented by R. At times other letters are used, which refer to the private nomenclature of manufacturers.

Considered from the standpoint of chemical constitution there are many classes of dyes. Only a few of the more important classes will be described here.

533. Nitro-Dyes. — Many of the nitro derivatives of phenols possess marked colors, and are useful as dyes. Among these are *picric acid* (*trinitrophenol*), *naphthol yellow*, which is a salt of dinitro-α-naphthol, and *naphthol yellow S* or *brilliant yellow*, which is a sulphonic acid derivative of naphthol yellow.

AZO DYES

534. The dyes of this class are derived from azobenzene, $C_6H_5—N=N—C_6H_5$. They are prepared by treating a diazonium salt with an amine or a phenol. Thus, if a solution of *m*-phenylene diamine is added to a dilute solution of benzenediazonium chloride, the hydrochloride of di-amino-azobenzene, which is the dye *chrysoïdine*, is formed: —

$$C_6H_5.N_2.Cl + C_6H_4(NH_2)_2 = C_6H_5.N_2.C_6H_3(NH_2)_2.HCl$$

Similar condensations between diazonium salts and alkaline solutions of phenols yield hydroxyazo compounds: —

$$C_6H_5.N_2.NO_3 + C_6H_5ONa = C_6H_5.N_2.C_6H_4OH + NaNO_3$$

A great variety of dyes may be prepared by reactions analogous to those just given. It is possible to diazotize any primary aromatic amine and condense the resulting diazonium salt with amines and phenols. The condensation takes place readily only in the case where the diazo group replaces a hydrogen atom in the position para to the amino, substituted amino, or hydroxyl group. The dyes prepared in this way range in color from yellow to orange, red-brown, violet, and black.

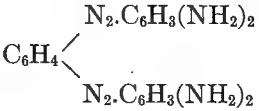
Aniline Yellow, $C_6H_5.N_2.C_6H_4NH_2.HCl$, is the simplest azo-dye. As the color is fugitive it is not now used as a dye. It forms, however, the starting point in the preparation of other dyes, as it can be diazotized and "coupled" with amines or phenols.

Butter Yellow, $C_6H_5.N_2.C_6H_4N(CH_3)_2$, is the dimethyl derivative of aniline yellow. It is chiefly used for coloring butter and oils.

Methyl Orange, $HSO_3.C_6H_4.N_2.C_6H_4N(CH_3)_2$, belongs to the class of *tropaeolins* which are yellow or orange sulphonated azo-dyes. Methyl orange (helianthine) is the sodium salt of the azo compound formed by condensing with dimethylaniline the diazo compound derived from sulphanilic acid. Silk and wool are dyed a bright orange color when immersed in an acid solution of helianthine. The free sulphonic acid is a valuable indicator in titrating acids and bases.

Bismarck Brown is the hydrochloride of the compound formed by the action of nitrous acid on *m*-phenylene diamine. A part of the amine is converted into a diazonium salt, which immediately condenses with more of the amine to form an azo compound. The two formulas given below have been assigned to the dye prepared in this way:—

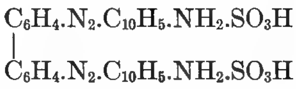
$H_2N.C_6H_4.N_2.C_6H_3(NH_2)_2$ and



$$C_6H_4\begin{cases} N_2.C_6H_3(NH_2)_2 \\ N_2.C_6H_3(NH_2)_2 \end{cases}$$

Bismarck brown is much used for dyeing leather. The dye is formed when *m*-phenylene diamine is treated in aqueous solution with a trace of nitrous acid; it thus serves as a test for nitrites in water analysis.

Congo Red is a tetrazo dye derived from benzidine. It is prepared by condensing the diazo compound from this amine with naphthionic acid, $C_{10}H_6NH_2.SO_3H(1, 4)$, and has the following formula: —

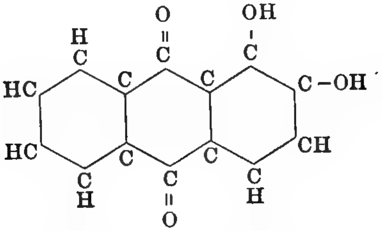


$$\begin{array}{l} C_6H_4.N_2.C_{10}H_5.NH_2.SO_3H \\ | \\ C_6H_4.N_2.C_{10}H_5.NH_2.SO_3H \end{array}$$

A solution of congo red is blue in the presence of acids and red in the presence of bases. The dye colors cotton a bright crimson red, but the color is not permanent; wool is dyed a bright scarlet.

OXYKETONE DYES

535. Alizarin, $C_6H_4(CO)_2C_6H_2(OH)_2$, the most important member of the oxyketone dyes, is the dihydroxyanthraquinone of the structure, —



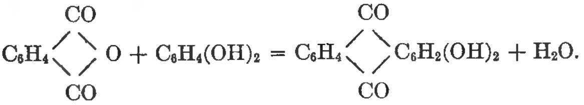
Alizarin occurs as a glucoside, ruberythric acid, $C_{26}H_{28}O_{14}$, in madder-root, from which the dye was formerly obtained. It is now manufactured from anthracene. The preparation of the dye involves the oxidation of anthracene to anthraquinone, the sulphonation of the latter, and the fusion of the resulting anthraquinone-monosulphonic acid with sodium hydroxide. Potassium nitrate or potassium chlorate is added to the mixture to be fused in order to prevent the reduction of the alizarin by the hydrogen formed during the reaction, which takes place according to the following equation: —

$$C_6H_4(CO)_2C_6H_3SO_3Na + 3NaOH = C_6H_4(CO)_2C_6H_2(ONa)_2 + Na_2SO_3 + H_2O + H_2$$

When the product of the fusion is acidified, alizarin is precipitated.

Alizarin crystallizes from alcohol in reddish-yellow prisms which melt at 289°–290°, and sublimes at a higher temperature in orange needles. Solutions of the sodium salt of alizarin give colored precipitates called "lakes" with solutions of the salts of most metals. The precipitates with barium and calcium salts are purple, and those with aluminium and tin are red; ferrous salts yield violet, and ferric salts black-violet, precipitates. The color of a fabric dyed with alizarin is thus determined by the metallic salt used as the mordant. Turkey-red, for example, is dyed by a series of operations involving the use of aluminium salts and an oil which furnishes fatty acids.

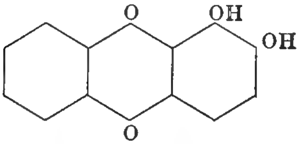
536. Alizarin is reduced to anthracene when heated with zinc-dust — a transformation which was the first step taken in determining the structure of the dye contained in madder-root. The view that alizarin is a dihydroxyl derivative of anthraquinone, follows from the fact that it is formed as the result of the fusion of anthraquinone-sulphonic acid with caustic alkalies, and from the synthesis of the dye by heating phthalic anhydride and pyrocatechol with sulphuric acid at 150°: —



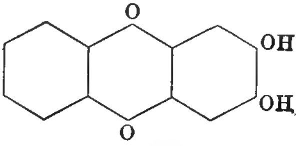
$$C_6H_4\left\langle\begin{array}{c}CO\\ \\ CO\end{array}\right\rangle O + C_6H_4(OH)_2 = C_6H_4\left\langle\begin{array}{c}CO\\ \\ CO\end{array}\right\rangle C_6H_2(OH)_2 + H_2O.$$

The formation of alizarin from pyrocatechol indicates that the hydroxyl groups are in the ortho position, and that the structure of the dye should be represented by either of the following formulas: —

(I)



(II)



A study of the products which result from the nitration of alizarin, shows that formula (I) is correct. In the two mononitro derivatives formed, the nitro group is in combination with the ring to which the hydroxyl groups are joined, since the two derivatives yield phthalic acid on oxidation. As a compound of the structure represented by formula (II) could not yield two such mononitro derivatives, the conclusion is drawn that the structure of alizarin is that indicated by formula (I).

537. A number of derivatives of alizarin are used as dyes. Among these are *alizarin carmine*, which is the sodium salt of the monosulphonic acid derived from alizarin, and *alizarin orange*, which is nitroalizarin. *Anthragallol*, the essential constituent of anthracene brown, has the structure $C_6H_4(CO_2)C_6H(OH)_3$ (1, 2, 3). *Purpurin*, which occurs with alizarin in old madder-root, and can be prepared by oxidizing alizarin with manganese dioxide and sulphuric acid, is an isomer of anthragallol in which hydroxyl groups are in the positions 1, 2, 4.

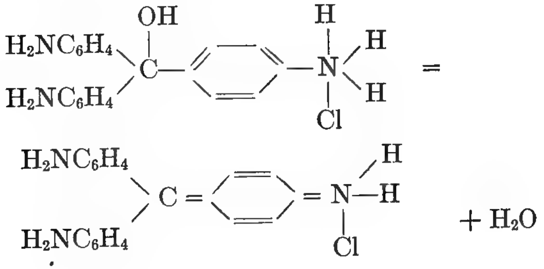
TRIPHENYLMETHANE DYES

538. In 1856 Perkin discovered accidentally in an investigation which had as its aim the synthesis of quinine, that a violet dye was formed when aniline containing toluidine was oxidized with chromic acid. The manufacture of this dye, which was called *mauve*, marked the beginning of the coal-tar color industry. In 1859 Hofmann prepared magenta by oxidizing a mixture of aniline, *o*-toluidine, and *p*-toluidine with less active oxidizing agents than chromic acid, such as nitrobenzene and mercuric chloride. An investigation of the structure of magenta by E. and O. Fischer showed later that the dye was a derivative of triphenylmethane.

The dyes of this group are not prepared from triphenylmethane, but the synthesis of pararosaniline from the hydrocarbon is of importance, as it established the structure of this dye which is the simplest member of the class. The steps involved in the transformation of triphenylmethane into pararosaniline are indicated by the following formulas: —

$$(C_6H_5)_3CH \rightarrow (NO_2C_6H_4)_3CH \rightarrow (NH_2C_6H_4)_3CH \rightarrow (NH_2C_6H_4)_3COH$$

Triphenylmethane is converted by cold fuming nitric acid into a trinitro derivative, in which the nitro groups are in the para positions to the methane carbon atom. Reduction converts this compound into the corresponding amine, which is changed by mild oxidizing agents into triamino-triphenylcarbinol. This substance, also called pararosaniline, when treated with acids, yields highly colored salts, which are dyes. The formation of the salt and the attendant production of color takes place with the elimination of one molecule of water when equal molecular quantities of the base and acid are used. The manner in which the water is eliminated and the structure of the resulting salt, have been the subject of much investigation. The view generally accepted at present is that indicated by the formula given below: —



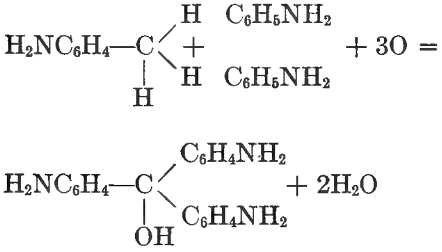
It is believed that hydrochloric acid adds to one amino group, and that the elimination of water then takes place in such a way that a quinoid ring is formed. A change in the reverse direction occurs when an alkali is added to a salt of pararosaniline; the salt is decomposed and the free base is formed.

The triphenylmethane dyes are salts formed by the action of acids on certain derivatives of triphenylcarbinol. For this reason these derivatives are called "color-bases," although they are, themselves, colorless. By reduction the color-bases are converted into the so-called "leuco-bases" which are formed as the result of the replacement of the hydroxyl group of the carbinol by hydrogen. The leuco-bases may be oxidized to the color-bases. In the case of pararosaniline the bases have the following formulas: —

$(H_2NC_6H_4)_3C.H$	$(H_2NC_6H_4)_3C.OH$
leuco-base	color-base

The methods used to prepare the dyes of this class may be illustrated by a consideration of pararosaniline, rosaniline, methyl violet, crystal violet, and malachite green.

539. Pararosaniline is obtained by heating *p*-toluidine and aniline, in the molecular proportion of one of the former to two of the latter, with a mild oxidizing agent such as arsenic acid or nitrobenzene. The methyl group of the toluidine furnishes the so-called methane carbon atom: —



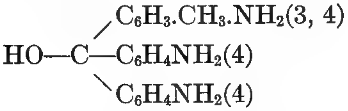
$$H_2NC_6H_4{-}\underset{\displaystyle H}{C}\begin{array}{l}\diagup H \quad C_6H_5NH_2\\ \quad +\\ \diagdown H \quad C_6H_5NH_2\end{array} + 3O =$$

$$H_2NC_6H_4{-}\underset{\displaystyle OH}{C}\begin{array}{l}\diagup C_6H_4NH_2\\ \\ \diagdown C_6H_4NH_2\end{array} + 2H_2O$$

The color-base dissolves in acids to form a red dye; it may be precipitated from the solution by alkalies.

Pararosaniline can be converted into triphenylmethane; the color-base is reduced by zinc and hydrochloric acid to the leuco-base, triamino-triphenylmethane, which in turn is converted into triphenylmethane as the result of the replacement of the amino groups by hydrogen through the use of the diazo reaction.

Rosaniline is the color-base of *magenta.* The hydrochloride of the base is generally called magenta or fuchsine, although the acetate is used under these names. Rosaniline is manufactured by oxidizing a mixture of aniline, *o*-toluidine, and *p*-toluidine, with arsenic acid, mercuric nitrate, or nitrobenzene. The reaction is analogous to that which takes place in the preparation of pararosaniline, of which rosaniline is a methyl derivative with the structure indicated by the following formula: —



$$\begin{array}{l} \qquad\quad\diagup C_6H_3.CH_3.NH_2(3,\,4) \\ HO-C-C_6H_4NH_2(4) \\ \qquad\quad\diagdown C_6H_4NH_2(4) \end{array}$$

Acid magenta, or *fuchsin S,* is the sodium salt of the trisulphonic acid obtained by heating rosaniline with fuming sulphuric acid.

540. Methyl Violet B. — By the partial or complete substitution of the hydrogen atoms of the amino groups in pararosaniline and rosaniline by methyl or ethyl groups, violet dyes are obtained, those containing the larger number of alkyl groups yielding the bluer shades. Methyl violet B, which is the hydrochloride or the double zinc chloride of pentamethyl-pararosaniline, is prepared by oxidizing dimethylaniline with cupric chloride.

Crystal Violet. — The preparation of this dye, which is the chloride of hexamethyl-pararosaniline, illustrates a method of preparing dyes of this class. The compound is manufactured by treating dimethylaniline with carbonyl chloride or tetramethyl-diamino-benzophenone chloride: —

$$[(CH_3)_2NC_6H_4]_2CCl_2 + C_6H_5N(CH_3)_2 = \\ ClC[C_6H_4N(CH_3)_2]_3 + HCl$$

The compound formed in this way probably rearranges into one which possesses a quinoid formula similar to that assigned to the salts of pararosaniline.

Rosaniline Blue. — The introduction of phenyl radicals into the amino groups of rosaniline and pararosaniline leads to the formation of blue-violet and blue dyes. Rosaniline blue is a salt of triphenyl-rosaniline; it is prepared by heating rosaniline to about 180° with about ten times its weight of aniline and some benzoic acid.

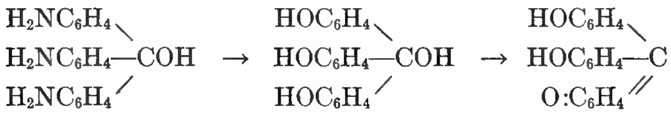
541. Malachite Green is an example of a dye derived from diamino-triphenylmethane. It is prepared by heating benzoic aldehyde with dimethylaniline in the presence of a dehydrating agent, and oxidizing the resulting compound with lead peroxide. The formation of the leuco-base takes place according to the following equation: —

$$C_6H_5.CHO + 2C_6H_5N(CH_3)_2 = C_6H_5.CH[C_6H_4N(CH_3)_2]_2 + H_2O$$

The base, which is a tetramethyl-diamino-triphenylmethane, is oxidized to the corresponding carbinol. The dye is usually sold as the double zinc salt, $3C_{23}H_{24}N_2HCl.2ZnCl_2.2H_2O$.

Victoria Green 3 B is a chlorinated malachite green prepared from dichlorbenzoic aldehyde and dimethylaniline. The introduction of halogen leads to the formation of a dye which yields bluer shades of green than malachite green. The sulphonic acid derivatives of these dyes, as well as those derived from dimethylaniline, are also manufactured.

542. Rosolic Acid Derivatives. — Certain hydroxyl derivatives of triphenylmethane are highly colored compounds and serve as useful dyes. The structure of these compounds is analogous to that of pararosaniline. When the amino groups of pararosaniline are replaced by hydroxyl groups by means of the diazo reaction, trihydroxy-triphenylcarbinol is first formed and then loses water and passes into *aurin* (pararosolic acid): —

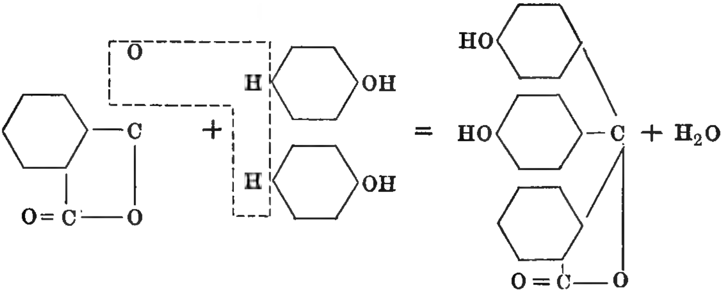


$$\begin{array}{l} H_2NC_6H_4\diagdown \\ H_2NC_6H_4{-}COH \\ H_2NC_6H_4\diagup \end{array} \rightarrow \begin{array}{l} HOC_6H_4\diagdown \\ HOC_6H_4{-}COH \\ HOC_6H_4\diagup \end{array} \rightarrow \begin{array}{l} HOC_6H_4\diagdown \\ HOC_6H_4{-}C \\ O{:}C_6H_4{/\!/} \end{array}$$

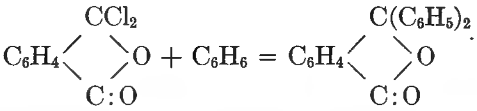
Aurin is a red crystalline compound which forms salts with acids and bases. The sodium salt of aurin is the *yellow corallin* of commerce. The dye is prepared by heating a mixture of phenol, sulphuric acid, and oxalic acid.

Rosolic Acid is the methyl derivative of aurin, which bears the same relation to rosaniline that aurin bears to pararosaniline. Derivatives of these coloring matters which contain nitro groups and carboxyl groups are also used as dyes.

543. Phthaleins. — Phenolphthalein, which is prepared by heating a mixture of phenol and phthalic anhydride with a dehydrating agent, is a derivative of triphenylmethane. The equation for the reaction is as follows: —

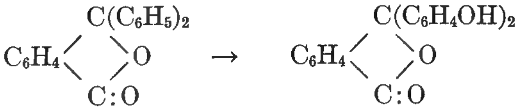


The structure of phenolphthalein has been established by its synthesis from diphenylphthalid (see phthalid **472**), which is prepared from phthalyl chloride and benzene by the Friedel and Crafts reaction: —



$$C_6H_4\left\langle\begin{matrix}CCl_2\\ \\ C{:}O\end{matrix}\right\rangle O + C_6H_6 = C_6H_4\left\langle\begin{matrix}C(C_6H_5)_2\\ \\ C{:}O\end{matrix}\right\rangle O$$

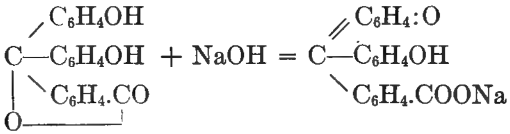
When diphenylphthalid is treated with nitric acid a dinitro derivative is formed. When the nitro groups are replaced by hydroxyl groups by reduction and the diazo reaction, the resulting compound is phenolphthalein: —



$$C_6H_4\left\langle\begin{matrix}C(C_6H_5)_2\\ \\ C{:}O\end{matrix}\right\rangle O \rightarrow C_6H_4\left\langle\begin{matrix}C(C_6H_4OH)_2\\ \\ C{:}O\end{matrix}\right\rangle O$$

Phenolphthalein is a colorless compound which yields pink salts with alkalies, and is a valuable indicator in acidimity. It is very sensitive to hydrogen ions and is, accordingly, suited to the titration of the weak organic acids.

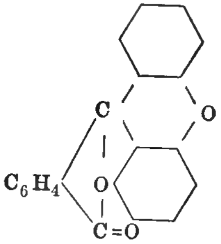
When phenolphthalein is converted into salts by alkalies, a molecular rearrangement takes place as the result of which a compound containing a quinoid group is formed: —



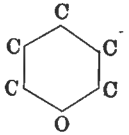
$$\underset{\mathrm{O}\text{———————}|}{\mathrm{C}}\begin{array}{l}/\mathrm{C_6H_4OH}\\ -\mathrm{C_6H_4OH}\\ \backslash\mathrm{C_6H_4.CO}\end{array} + \mathrm{NaOH} = \mathrm{C}\begin{array}{l}/\!/\mathrm{C_6H_4{:}O}\\ -\mathrm{C_6H_4OH}\\ \backslash\mathrm{C_6H_4.COONa}\end{array}$$

The color of the salts of phenolphthalein and related compounds is considered to be due to the presence in them of the chromophore group $:C_6H_4:O$.

544. Fluoran is formed as a by-product in the preparation of phenolphthalein. In the formation of this compound the condensation of phthalic anhydride with phenol takes place in such a way that the hydrogen atoms eliminated from the phenol are those in the ortho position to the hydroxyl group, whereas in the case of phenolphthalein the hydrogen atoms involved are the ones in the para position. The product formed in this way loses water and the result is fluoran, which has the structure indicated by the following formula: —

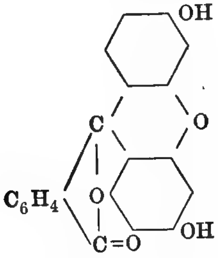


Fluoran dissolves in alkalies to form fluorescent solutions, — that is, solutions which exhibit different colors in transmitted and reflected light. It has been shown that many compounds containing the pyrone ring,



which is present in fluoran, fluoresce.

545. Fluorescein is a dihydroxyl derivative of fluoran, which is prepared by heating phthalic anhydride with resorcinol. The structure assigned to the compound is as follows: —



Dilute solutions of fluorescein in alkalies exhibit a brilliant yellow-green fluorescence.

A number of derivatives of fluorescein are useful dyes. *Chrysolin* or *uranin* is benzyl-fluorescein, which is formed from phthalic anhydride and benzyl-resorcinol. It dyes silk and wool a fast yellow, and is used in cotton dyeing. *Eosin*, tetrabrom-fluorescein, is prepared by the action of bromine on fluorescein. Its dilute alkaline solution is rose-colored, and exhibits an intense yellow-green fluorescence. Other dyes related to fluorescein are tetrabrom-dichlorofluorescein and various ethers of fluorescein and its substitution-products. The dyes of this class produce on silk and wool shades from yellow to reddish yellow, cherry-red, and purple.

CHAPTER XXIX

TERPENES AND CAMPHORS

546. The hydrocarbons of the composition $(C_5H_8)_x$ present in plants are called terpenes. The more important members of the class have the formula $C_{10}H_{16}$, and are obtained from the sap of coniferous trees and from fruits of the citrus variety; they are the principal constituents of oil of turpentine and of many essential oils. With few exceptions the terpenes are liquids; some are optically active. They polymerize when treated with sulphuric acid, and form addition-products with bromine, hydrochloric acid, and water. The terpenes can be converted into cymene, and like this hydrocarbon yield *p*-toluic acid and terephthalic acid when oxidized.

The terpenes and their derivatives have been carefully studied in an endeavor to determine the relation which exists between the structural configurations of these important substances. Some of the hydrocarbons are unsaturated aliphatic compounds; to this class belong isoprene, C_5H_8 (**45**), which is called a hemiterpene, and anhydrogeraniol,

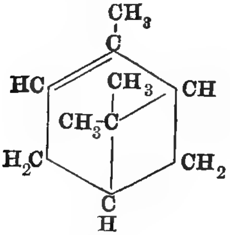
$$(CH_3)_2C:CH.CH_2.CH_2.C(CH_3):C:CH_2,$$

of which geranial (**154**) is a derivative. Most of the terpenes, however, are *alicyclic compounds*, that is, ring compounds of carbon that do not possess the so-called aromatic properties (**352**). Some of these are derivatives of the hydroaromatic hydrocarbons (**346**); others are related to these hydrocarbons but contain two rings. On account of the complexity of the subject it is impossible to discuss briefly the evidence in favor of the constitutional formulas which have been assigned to the terpenes.

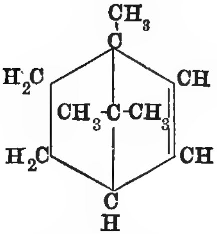
547. Pinene, $C_{10}H_{16}$, is the principal constituent of the oil of turpentine; that obtained from the American oil is dextrorotatory, and that from the German and French oils is levorotatory.

Turpentine, which is the sap of coniferous trees, contains in addition to terpenes a non-volatile compound of unknown structure, called abietic anhydride. When the sap is distilled with steam, there are obtained oil of turpentine and abietic acid, $C_{19}H_{28}O_2$, which is non-volatile; when the distillation is made without steam the residue is called *rosin* or *colophony*. Pinene is the fraction of oil of turpentine which boils at 156°; it has the specific gravity 0.86 at 25°. Pinene is present in the oils of rosemary, lemon, sage, juniper, thyme, and anise, and in other essential oils.

Pinene forms with one molecule of dry hydrogen chloride, an addition-product, which is called artificial camphor (m.p. 125°) on account of the fact that it resembles camphor in appearance and odor. When this compound is heated with alcoholic potash or with a mixture of anhydrous sodium acetate and glacial acetic acid, hydrogen chloride is eliminated and *camphene*, an isomer of pinene, is formed. Camphene melts at 50°; it is converted into camphor $C_{10}H_{16}O$ (**550**) when oxidized with chromic acid. The structural formulas assigned to pinene and camphene are as follows: —



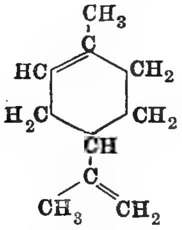
Pinene



Camphene

548. Limonene, $C_{10}H_{16}$, occurs in two optically active varieties; the dextro-compound (b.p. 175°) is present in the oils obtained from oranges, lemons, and caraway. *l*-Limonene is obtained from the oil distilled from the leaves of a variety of pine. When the two varieties are mixed in equal amounts the racemic modification formed is identical with *dipentene*, a compound which is formed when pinene and other terpenes are heated to a high temperature. Dipentene occurs in the volatile oil of the camphor tree and in Russian and Swedish turpentines.

The limonenes add two molecules of hydrogen chloride and four atoms of bromine, and form crystalline addition-products with nitrosyl chloride, NOCl. The formula assigned to limonene is: —



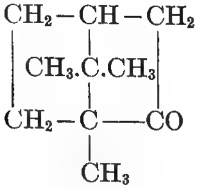
This formula is in accord with the fact that the hydrocarbon can be converted into cymene (**356**), that it unites with two molecules of hydrogen chloride, and that it exists in optically active modifications, one of the carbon atoms of the ring being asymmetric.

Camphors

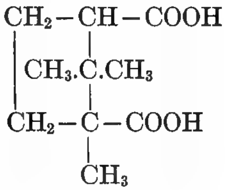
549. The camphors are oxygen derivatives related to the terpenes; they have the formula $C_{10}H_{16}O$, $C_{10}H_{18}O$, and $C_{10}H_{20}O$, are associated with terpenes in plants, and are constituents of many essential oils. The camphors are solid crystalline substances, which are volatile with steam, sublime at low temperatures, and possess characteristic odors. Like the terpenes they are readily converted into benzene derivatives; when ordinary camphor is warmed with phosphorus pentoxide cymene is formed.

550. **Camphor**, $C_{10}H_{16}O$, sometimes called Japan camphor or laurinol, is obtained by distilling with steam the wood or leaves of the camphor tree; it melts at 176°–177°, boils at 209°, and is dextro-rotatory. The chemical properties of camphor are those of a ketone; it forms an oxime with hydroxylamine, its oxygen atom is replaced by two chlorine atoms when it is treated with phosphorus pentachloride, and it is converted by reducing agents into borneol, which is a secondary alcohol. By the loss of water camphor passes into cymene (**356**), and by the loss of two hydrogen atoms into carvacrol (**447**). The chief product of the oxidation of camphor is camphoric acid,

$C_{10}H_{16}O_4$. The formulas assigned to these two substances are as follows: —



Camphor



Camphoric acid

Camphene (**547**) is converted by oxidation into camphor; the relation between the compounds is clear from the structural formulas which have been given.

Among the compounds isomeric with camphor may be mentioned *fenchone*, which is present in fennel oil, and *pulegone* which is a constituent of the oil of pennyroyal.

551. Borneol, $C_{10}H_{18}O$, (m.p. 208°) is a camphor which is found in certain trees grown in Borneo and Sumatra; it is also present in the oil of valerian and the oil of rosemary. As has been stated, it is formed by reducing ordinary camphor. It yields camphor on oxidation and is converted by dehydrating agents into camphene. It is, accordingly, the secondary alcohol formed by reducing the carboxyl group in camphor.

Cineol, terpineol, and *thujone* are isomers of borneol which occur in certain essential oils. *Menthol,* mint-camphor, $C_{10}H_{20}O$, the chief constituent of the oil of peppermint, has been mentioned (**378**).

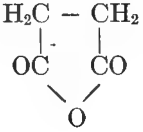
CHAPTER XXX

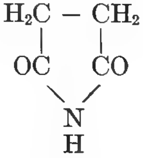
HETEROCYCLIC COMPOUNDS

552. Compounds which contain atoms joined in a ring are classified as *homocyclic* or *heterocyclic* compounds; to the former class belong the substances in which the ring is made up of atoms of but one element, and to the latter, those containing two or more elements in the ring. Benzene and naphthalene are homocyclic compounds; as the rings in these cases consist of carbon atoms, the hydrocarbons are sometimes called *carbocyclic* compounds. Succinic anhydride and succinimide are heterocyclic compounds as the rings present in these substances contain oxygen and nitrogen, respectively, in addition to carbon.

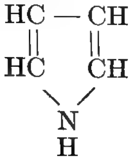
Many heterocyclic compounds of complex structure occur in nature, and many have been synthesized. Most of the basic nitrogenous substances which occur in plants and are known as alkaloids are heterocyclic compounds. When coal is subjected to destructive distillation a part of the nitrogen present is converted into ammonia, and a part into cyclic compounds which contain nitrogen as a constituent of the ring. Heterocyclic compounds are also obtained from "Dippel's oil," which is a product of the distillation of bones. From these sources are obtained pyridine, C_5H_5N, picoline, $CH_3.C_5H_4N$, quinoline, C_9H_7N, etc.

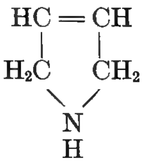
553. It is possible to prepare ring-compounds of many types as the result of the elimination of atoms or groups from straight-chain compounds, the formation of rings containing five or six atoms being most easily accomplished. It will be recalled that succinic acid is converted into its anhydride when heated, and that succinamide under similar conditions yields succinimide. The formulas of these compounds are as follows: —

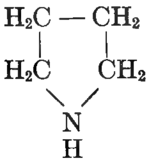




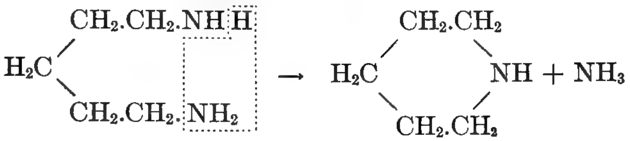
By reduction succinimide may be converted into compounds of the following formulas: —


Pyrrole

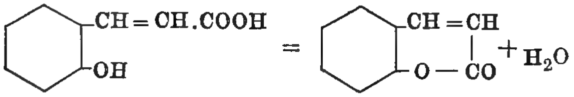

Pyrroline
(dihydropyrrole)


Pyrrolidine
(tetrahydropyrrole)

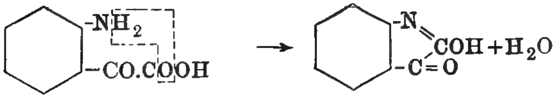
Ring-compounds are formed when the salts of certain diamines are distilled. In this way piperidine is formed from pentamethylene diamine: —



Ring-compounds are also readily formed from ortho derivatives of benzene. Thus, *o*-hydroxycinnamic acid loses water and passes into coumarin, a constituent of tonka beans, which is used in the preparation of perfumery and as an adulterant in vanilla extract: —



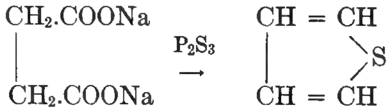
o-Aminobenzoylformic acid loses water spontaneously and isatin is formed: —



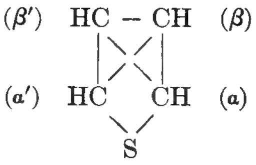
A great variety of heterocyclic compounds containing nitrogen or other elements have been investigated, but only a few will be described here.

554. Thiophene, C_4H_4S, is present to the extent of about 0.5 per cent in the crude benzene obtained from coal-tar. It is a liquid which resembles benzene closely in physical and chemical properties; it boils at 84° and has the specific gravity 1.07 at $\frac{15^\circ}{4^\circ}$. When thiophene is treated with isatin (**568**) and sulphuric acid a blue coloration is formed. The production of color in this way, the so-called indophenin reaction, led to the discovery of thiophene by Victor Meyer. Before thiophene was discovered it was thought that the reaction was characteristic of benzene. A certain sample of the hydrocarbon failed to give the test. On investigation it was found that the benzene used had been prepared from benzoic acid. As benzene obtained from coal-tar gave the test, it was evident that the color-reaction was produced by a substance mixed with the hydrocarbon. When benzene containing thiophene is shaken with concentrated sulphuric acid, the thiophene is more rapidly converted into a sulphonic acid than is the benzene. Thiophene is obtained from the sulphonic acid prepared in this way by heating the latter with water under pressure.

555. Thiophene has been synthesized by heating sodium succinate with phosphorus trisulphide: —

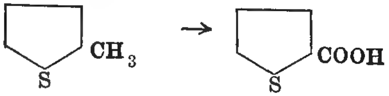


The structure of thiophene has been deduced from this and other syntheses. As the compound resembles closely benzene in chemical properties, a centric formula similar to that of benzene has been proposed for thiophene: —

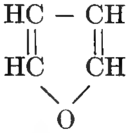


Thiophene possesses the characteristics of aromatic compounds; it is converted into nitro compounds by nitric acid, into halogen derivatives by bromine and chlorine, into sulphonic acids by sulphuric acid, and condenses with acyl chlorides in the presence of aluminium chloride to form a ketone. It will be recalled that compounds which behave in this way are classed as aromatic.

Homologues of thiophene occur in coal-tar; they may be prepared by Fittig's synthesis and in other ways. Their properties are similar to those of the analogous benzene derivatives; for example, thiotolene, methyl thiophene, is converted into thiophene carboxylic acid by oxidizing agents: —

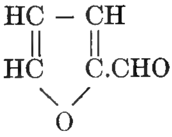


556. Furfuran, C_4H_4O, resembles thiophene in structure, the sulphur atom in the latter being replaced by oxygen: —



It occurs in pine-wood tar, and is formed in small quantities when cane sugar is distilled with lime; it boils at 32°.

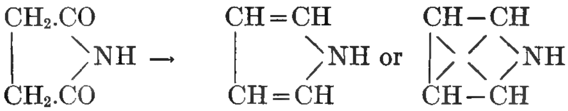
557. Furfuraldehyde, $C_4H_3O.CHO$, is an aldehyde derived from furfuran. Its syntheses and reactions lead to the conclusion that it has the structure represented by the following formula: —



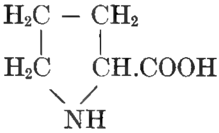
Furfuraldehyde, which is also called furfural or furfurole, is formed when pentoses are heated with dilute sulphuric acid or dilute hydrochloric acid. It yields an intense red dye when treated with aniline and hydrochloric acid; it serves, thus, as a convenient test for pentoses and pentosans. Furfuraldehyde is a liquid which possesses an agreeable odor and boils at 162°. It possesses the characteristic properties of an aromatic aldehyde.

558. Pyromucic acid, $C_4H_3O.COOH$, is formed as the result of the oxidation of furfuraldehyde. As its name implies it is produced by the distillation of mucic acid, $COOH(CHOH)_4COOH$.

559. Pyrrole, $C_4H_4.NH$, occurs in coal-tar and in bone-oil. It is formed as the result of the distillation of the ammonium salt of saccharic acid, and by the reduction of succinimide with zinc dust: —



Pyrrole is an oil with a fragrant odor resembling that of chloroform; it boils at 131° and has the specific gravity 0.967 at $\frac{21°}{4°}$. It imparts a carmine-red coloration to pine-wood shavings in the presence of hydrochloric acid. Pyrrole is a weak base and possesses to some extent the properties of a secondary amine. When warmed with potassium hydroxide it yields the compound $C_4H_4.NK$. Pyrrole is obtained as one of the decomposition-products of proteins (**579**). It yields on reduction pyrroline, $C_4H_6.NH$, and pyrrolidine, $C_4H_8.NH$. The carboxyl derivative of the latter having the formula

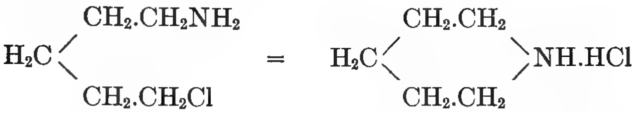


is known as proline; it is formed as the result of the hydrolysis of many proteins.

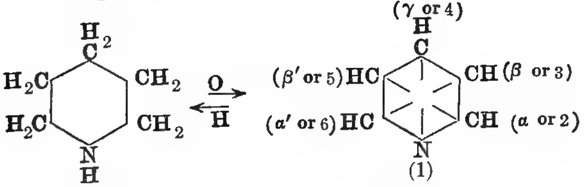
560. Pyridine, C_5H_5N, and its homologues are the basic constituents of the "light-oil" (**344**) obtained from coal-tar distillate. They are separated from the hydrocarbons in the oil by treating the latter with sulphuric acid. The pyridine bases which dissolve are recovered from solution by treatment with an alkali. Pyridine is also obtained from bone-oil. When bones which have not been deprived of adhering fat are subjected to distillation, an oil that contains a large number of nitrogen compounds is obtained. When heated to the temperature used in the distillation, the fat present is, in part, converted into acrolein, which yields nitrogenous compounds with the ammonia and other basic substances formed as the result of the decomposition of the proteins present in the bones. Pyridine is present in tobacco smoke and in small quantities in commercial ammonia.

Pyridine is a liquid, miscible with water, which possesses a characteristic, unpleasant odor; it boils at 116° and has the specific gravity 0.985 at 15°.

561. Pyridine has been synthesized in a number of ways which lead to definite views of its structure. When an aqueous solution of ε-chloramylamine is warmed, the hydrochloride of piperidine, tetrahydropyridine, is formed. This fact and other syntheses lead to the view that the reaction that takes place is best interpreted as follows: —



As piperidine can be oxidized to pyridine, and pyridine is readily reduced by sodium and alcohol to piperidine, the relation between the two compounds is assumed to be that represented by the following formulas: —



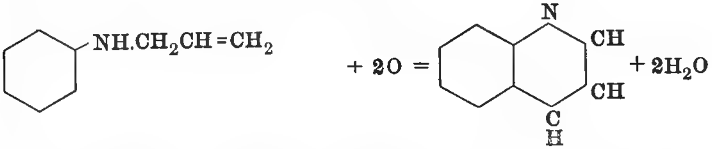
piperidine pyridine

Pyridine is a tertiary amine; its aqueous solution shows an alkaline reaction and precipitates the hydroxides of metals, some of which are soluble in an excess of the amine. Salts of pyridine like those of other amines form characteristic double salts with metallic halides. The ferrocyanide of pyridine and the addition-product of pyridine and mercuric chloride are difficultly soluble in water; these compounds are used in the purification of the base. Pyridine is a very stable compound; it can be heated with nitric acid or chromic acid without undergoing change; at a high temperature it is converted into a sulphonic acid by sulphuric acid. Chlorine and bromine form addition-products, e.g., $C_5H_5N.Cl_2$, at the ordinary temperature; when these are heated to above 200°, substitution-products are formed.

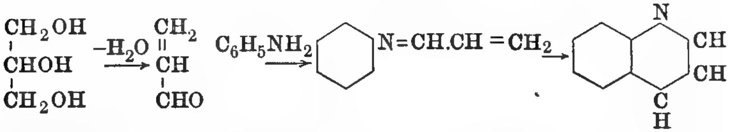
562. Homologues of Pyridine. — Many homologues of pyridine have been obtained from bone-oil and coal-tar or by syntheses from other compounds. The methyl derivatives of pyridine are called *picolines*, the dimethyl derivatives are called *lutidines*, and the trimethyl derivatives are called *collidines*. As in the case of toluene and the xylenes, the side-chains are converted into carboxyl groups by oxidation. The α, β, and γ mono-carboxylic acids of pyridine are called picolinic acid, nicotinic acid, and isonicotinic acid, respectively.

563. Quinoline, C_9H_7N, is one of the products of the destructive distillation of quinine; it is present in coal-tar and bone oil. Quinoline is a liquid of characteristic odor, which boils at 238° and has the specific gravity 1.108 at 0°.

Quinoline has been synthesized by methods which lead to a definite view of its structure. It is formed when allyl aniline is passed over heated lead oxide: —

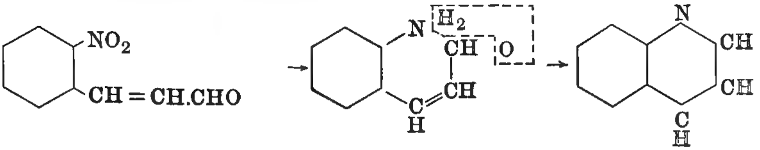


In the Skraup synthesis quinoline is formed by heating together aniline, glycerol, and nitrobenzene in the presence of sulphuric acid, which acts as a dehydrating agent. It is possible that the glycerol is first converted into acrolein, which condenses with aniline to form acrolein-aniline; the latter is oxidized by the nitrobenzene to quinoline. These transformations are indicated by the following formulas: —

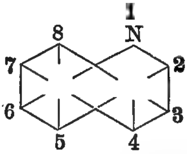


Homologues of quinoline have been prepared by replacing aniline by its substitution-products in the Skraup synthesis.

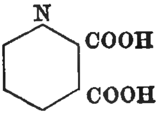
A third synthesis of quinoline is also of interest. When *o*-nitrocinnamic aldehyde is reduced, the amino-derivative formed spontaneously loses water and passes into quinoline: —



These syntheses indicate that the relation between the structure of quinoline and that of naphthalene is similar to that between the structures of benzene and pyridine; in both cases one CH group may be considered as replaced by a nitrogen atom. On account of the aromatic properties of quinoline the centric formula is usually assigned to it. The substitution-products are indicated, by assigning a number to each atom in the ring: —



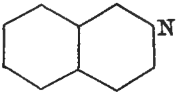
564. Quinoline shows the properties of a tertiary amine. As it contains a pyridine ring it resembles the latter in chemical properties. When oxidized the benzene ring is destroyed; the dibasic acid which is formed, called quinolinic acid, has the structure represented by the formula, —



Quinolinic acid is converted into nicotinic acid, β-pyridine carboxylic acid, when heated, and into pyridine when distilled with lime. These facts are additional evidence of the structure assigned to quinoline.

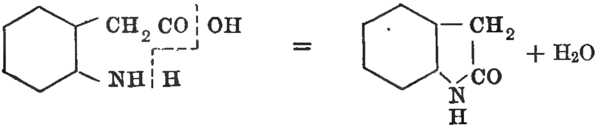
565. **Isoquinoline**, C_9H_7N, is present in coal-tar. Its odor is similar to that of quinoline; it melts at 21° and boils at 237°.

Syntheses of isoquinoline indicate that the structure should be represented by the following formula: —



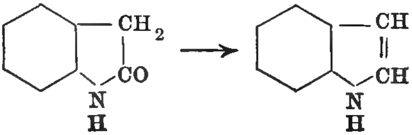
A number of alkaloids are derivatives of isoquinoline.

566. Indole, C_6H_7N, is of interest on account of its relation to indigo (**568**) and the fact that it is the product of the decomposition of certain proteins. Syntheses of indole lead to the conclusion that it is made up of a benzene nucleus condensed with a pyrrole nucleus. When *o*-nitro-phenylacetic acid is reduced with tin and hydrochloric acid the amino-phenylacetic acid formed loses water spontaneously and passes into oxindole:—



oxindole

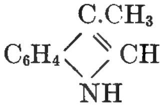
Oxindole is converted into indole when distilled with zinc dust: —



indole

Indole thus appears to be closely related to benzene and to pyrrole. Its chemical properties are in accord with this view of its structure. Indole is a weak base and like pyrrole gives a red coloration with a pine shaving which has been moistened with hydrochloric acid.

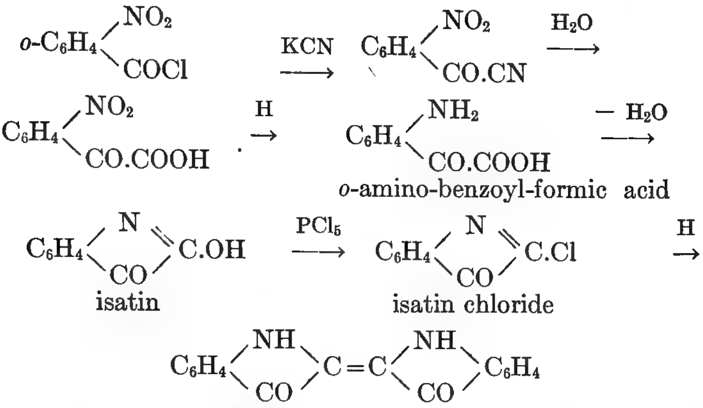
567. Skatole, which is *β*-methyl-indole,



$$C_6H_4\begin{array}{c}C.CH_3\\ \diagup\ \ \diagdown\!\!\diagdown \\ \diagdown\ \ \diagup \\ NH\end{array}CH,$$

is present in faeces, and is formed as the result of the putrefaction of certain proteins. It has a characteristic, disagreeable odor.

568. Indigo, $C_{16}H_{10}N_2O_2$, is a valuable blue dye, which is related in structure to the compounds just described. A number of syntheses of the dye which furnish evidence of its constitution have been effected; the one involving the preparation of indigo from isatin is important. The steps in the synthesis are indicated by the following formulas: —



o-amino-benzoyl-formic acid

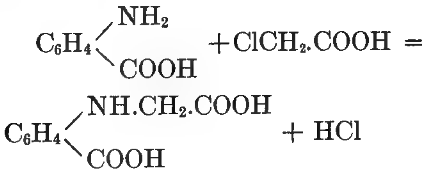
isatin

isatin chloride

indigo

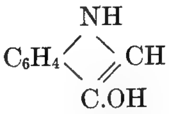
When *o*-nitro-benzoylformic acid is reduced the amino compound formed loses water spontaneously and passes into isatin. Reduction of isatin chloride with zinc and acetic acid yields indigo.

569. Indigo is manufactured in large quantities by a synthesis which involves the use of naphthalene and acetic acid. From the former anthranilic acid (**515**) is prepared and from the latter chloracetic acid. These compounds react to form phenylglycocol-*o*-carboxylic acid: —



$$C_6H_4\begin{matrix}\diagup NH_2\\ \diagdown COOH\end{matrix} + ClCH_2.COOH = C_6H_4\begin{matrix}\diagup NH.CH_2.COOH\\ \diagdown COOH\end{matrix} + HCl$$

Fusion with sodium hydroxide converts the acid into indoxyl,



which is oxidized to indigo in alkaline solution by air.

570. Indigo is obtained from the glucoside *indican*, $C_{14}H_{17}NO_6.3H_2O$, which occurs in certain plants grown in India, Java, and other countries. When the leaves of the indigo plant are stirred with warm water the glucoside is extracted. An enzyme present in the leaves converts this compound into glucose and indoxyl, which, in turn, is oxidized by the air to indigo. The product obtained in this way is a mixture of indigo blue (indigatin), indigo-brown, indigo-red, and other coloring matters. Indigatin is a dark-blue compound, insoluble in water and alcohol, which can be crystallized from aniline.

When indigo is treated with reducing agents it takes up two atoms of hydrogen and forms indigo-white, $C_{16}H_{12}N_2O_2$, a compound which dissolves in alkalies and is converted by air into indigo. The reducing agent often used is a solution of calcium hyposulphite, CaS_2O_4, which is prepared by treating zinc hyposulphite with lime. The fabric to be dyed is immersed in an alkaline solution of indigo-white and then exposed to the air, when the blue dye is formed.

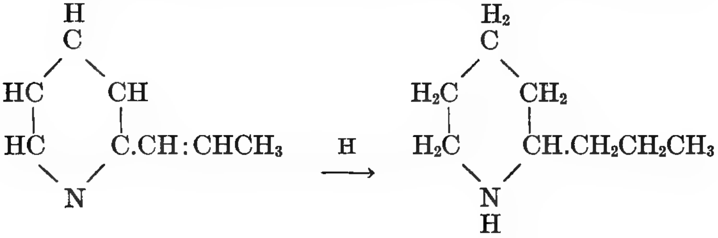
Alkaloids

571. The term alkaloid is applied to certain nitrogenous constituents of plants. The alkaloids differ widely in structure; some like muscarine (**175**) are aliphatic compounds, others like caffeine (**341**) contain a ring of carbon atoms and are related to uric acid. The alkaloids which are described briefly here are related to heterocyclic compounds, chiefly pyridine, quinoline, and isoquinoline. Most alkaloids have a marked physiological effect and many are poisonous; they are the so-called "active principles" of many plants.

With few exceptions the alkaloids are solids which are insoluble in water and crystallize from organic solvents. They are optically active and form salts with acids by direct addition, most of the alkaloids being tertiary amines. On account of the use of alkaloids in medicine their qualitative identification has been carefully studied. Most of the members of this class of compounds are precipitated from their solutions in acids by the so-called *general alkaloidal reagents;* among these are tannin, phosphomolybdic acid, phosphotungstic acid, picric acid, and potassium mercuric iodide and similar double salts. Many alkaloids give characteristic color reactions useful in their identification, when treated with acids, chlorine, and other inorganic reagents. Only a few compounds will be mentioned here.

572. Coniine, $C_8H_{17}N$, the alkaloid of hemlock, is of interest on account of the fact that it was the first natural alkaloid synthesized. Its preparation was effected by condensing α-picoline with aldehyde and reducing the resulting product by means of sodium and alcohol: —

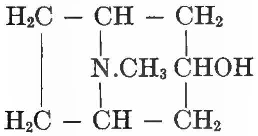
$$NC_5H_4.CH_3 + OHC.CH_3 = NC_5H_4.CH{:}CH.CH_3 + H_2O$$



The α-propyl-piperidine prepared in this way differed from coniine in being inactive. By the crystallization of the tartrate of the base two optically active forms were obtained; the dextrorotatory form proved to be identical with the natural alkaloid. Coniine is a colorless liquid which boils at 167°; it possesses a penetrating odor and is poisonous.

573. Nicotine, $C_{10}H_{14}N_2$, is the alkaloid of tobacco. It is a liquid which boils at 247° and is miscible with water; it is odorless when pure but on standing develops a tobacco-like odor and turns brown. Nicotine is converted by oxidizing agents into nicotinic acid, a fact which indicates that the alkaloid is a β-substitution-product of pyridine.

574. Atropine, $C_{17}H_{23}NO_3$, is the principal alkaloid of the deadly nightshade; it melts at 116°. It causes dilation of the pupil of the eye and is used by oculists. When heated with a solution of sodium hydroxide atropine yields tropine, $C_8H_{15}NO$, and tropic acid, $CH_2OH.CHC_6H_5.COOH$. The following formula is assigned to tropine: —



575. Cocaine, $C_{17}H_{21}NO_4$, is obtained from cocoa leaves. It is crystalline, melts at 98°, and is levo-rotatory. It is used as a local anæsthetic. Cocaine appears to be a derivative of tropine.

576. Quinine, $C_{20}H_{24}N_2O_2$, is the most important alkaloid of "Peruvian bark," from which twenty-four alkaloids have been isolated. Quinine melts at 177°. It is used as an antipyretic. Quinine appears to be a substitution-product of a compound made up of a quinoline ring in combination with a ring similar to tropine. It contains a methoxyl group, hydroxyl group, and two tertiary nitrogen atoms.

577. Strychnine, $C_{21}H_{22}N_2O_2$, is present in the seeds of *strychnos nux vomica.* It is excessively poisonous; in very small doses it is a powerful stimulant; larger doses cause death. which is preceded by violent contraction of the muscles. Strychnine melts at 265°. It is converted by fusion with potassium hydroxide into quinoline and indole, and by distillation with lime into *β*-picoline. *Brucine,* $C_{23}H_{26}N_2O_4$ occurs in *nux vomica* with strychnine, which it resembles in physiological effect.

578. Morphine, $C_{17}H_{19}NO_3$, is the principal alkaloid of opium, which contains a large number of substances, such as fats, resins, acids, and gums in addition to twenty alkaloids which have been identified. Opium is the dried juice of the seed capsules of the white poppy. Laudanum is an alcoholic extract of opium. Morphine, which melts at 230°, is used as a narcotic. When distilled with zinc-dust it yields phenanthrene, isoquinoline, pyridine, and pyrrole.

CHAPTER XXXI

PROTEINS

579. Under the general term protein are classed many complex nitrogenous organic compounds which occur abundantly in plants and animals. The proteins are of the greatest importance as they are present in all living cells, are essential to life-processes, and are a necessary constituent of animal foods. On account of their great complexity in composition our knowledge of the proteins is not as definite as that of many other compounds which occur in nature. The investigations of the molecular weights of proteins indicate that the number of atoms in the molecules of these substances is very great; the values obtained of the molecular weight of members of this group of compounds have varied from 500 to 15,000. It is evident that the determination of the structure of compounds of such complexity is a most difficult task.

580. Physical Properties of Proteins. — Most proteins are colorless, amorphous substances. They have no definite melting-points or boiling-points, but carbonize on heating and give off gases. The proteins differ widely from one another as to solubility in water, in solutions of salt, and in dilute alcohol. They are all insoluble in pure organic solvents. These differences in solubility were originally made the basis of a classification of proteins, for lack of a definite knowledge of the chemical nature of the substances upon which to base a chemical classification. Recent investigation has thrown much light on the chemical relationships existing between various classes of proteins, but in the modern classification difference in solubility is still retained as the most definite means of grouping certain of these compounds. Difference in solubility serves not only as a means of classification, but is of great value in the separation and purification of proteins.

The soluble proteins are precipitated from aqueous solutions by a large number of salts. These salts may be divided into two classes, namely, those, such as sodium chloride and ammonium sulphate, which precipitate (salt out) the protein in an unchanged condition, and those which form insoluble compounds with the protein, such as the salts of copper and silver. "Salting out" is an important means of separating proteins from complex mixtures obtained from animal and plant tissues and from one another, and has been the subject of much investigation. The salts which precipitate proteins unchanged differ in their action upon the various classes of these compounds. Ammonium sulphate and zinc sulphate precipitate not only the natural proteins but also all the products formed on the hydrolysis of the latter, except the peptones and amino-acids. When a solution containing proteins is saturated with magnesium sulphate, however, only the more readily precipitable compounds such as the so-called globulins are precipitated. This salt is, therefore, of value in effecting the separation of certain classes of proteins. Separation can also be effected by the fractional salting out with ammonium sulphate. This is accomplished by adding gradually increasing amounts of the salt to the solution containing the mixture of proteins. Each protein begins to precipitate when the concentration of the salt has reached a certain point, and at a certain higher concentration precipitation is complete. The precipitation-limits are defined as the number of cubic centimeters of a cold saturated ammonium sulphate present in 10 cc. of the liquid, when precipitation begins or ceases. Thus, the statement that the limits for a globulin are 2.9 and 4.6 means that when precipitation begins there is present in 10 cc. of the liquid enough ammonium sulphate to form 2.9 cc. of a saturated solution of the salt; likewise, when precipitation is complete, there is present in 10 cc. of the liquid enough of the sulphate to form 4.6 cc. of a saturated solution.

Proteins, like other colloidal substances, do not pass through semi-permeable membranes, such as parchment and collodion, and, consequently, can be separated from adhering inorganic salts by dialysis.

When alcohol is added to a solution of a protein, the latter is precipitated unchanged. If, however, the precipitate is allowed to stand in contact with strong alcohol for some time, a change takes place as the result of which the protein becomes insoluble in water. It is said to be coagulated. Coagulation is also produced by heat; this will be discussed later.

The solutions of all proteins are optically active. Most proteins are amorphous substances. Some have been obtained, however, in crystalline condition from pumpkin, hemp seed, castor seed, and Brazil nuts. Edestin, a well characterized protein which occurs in a number of seeds, can be crystallized from a warm 5 per cent solution of sodium chloride. Other proteins which do not occur in nature in a crystalline condition have been crystallized. Egg albumin, after precipitation from solution by ammonium sulphate and acetic acid, assumes a crystalline form on standing.

581. Chemical Properties of the Proteins. — The proteins that occur in nature may be divided into two main classes, the simple proteins, which resemble one another closely in chemical composition, and the so-called conjugated proteins, which are compounds of simple proteins with other complicated organic complexes. The conjugated proteins are readily decomposed into their constituents by mild chemical treatment, such as the action of cold hydrochloric acid.

The composition of the simple proteins will be first considered. These contain carbon, hydrogen, nitrogen, oxygen, and sulphur. It is a striking fact that the relative proportion in which these elements are present in simple proteins from widely different sources is so nearly alike. In the following table the results of the analyses of a few proteins are given.

COMPOSITION OF TYPICAL SIMPLE PROTEINS

Substance	Origin	C	H	N	S	O
Ov-albumin	Egg	52.75	7.10	15.51	1.62	23.02
Serum-albumin	Horse	52.93	7.05	15.89	1.82	22.31
Serum-globulin	Horse	52.71	7.01	15.85	1.11	23.32
Gelatin	Tendons	50.11	6.56	17.81	0.26	25.26
Keratin	Human hair	50.65	6.36	17.14	5.00	20.95
Gliadin	Wheat	52.72	6.86	17.66	1.03	21.73
Zein	Maize	55.23	7.26	16.13	0.60	20.78
Legumin	Peas	51.72	6.95	18.04	0.36	22.90

The percentage of carbon and hydrogen in simple proteins varies within comparatively narrow limits, but a greater variation is observed in the case of nitrogen and sulphur. The proteins from plants contain from two to three per cent more nitrogen than the simple animal proteins. Although the amount of sulphur present in proteins is relatively small, the variations in the amount are great. Egg albumin contains 1.62 per cent sulphur, the albumin of wheat 1.28, zein from maize 0.60, human hair 5.00, and human nails 2.80. Phosphorus is also present in certain proteins in small proportion; casein contains 0.85 per cent of this element. Iodine is a common constituent of the proteins of marine animals. Sponges yield a protein which contains 9 per cent of this halogen.

Many attempts have been made to determine the *molecular weight of proteins*, but the results obtained are not convincing. The percentage composition of a substance gives some idea as to the minimum molecular weight which it can possess. Egg albumin contains 1.6 per cent sulphur; if the molecule contains but one atom of this element the molecular weight is 2460. There is no reason for the belief, however, that but one sulphur atom is present in egg albumin. The determination of the molecular weight of this protein by the freezing-point method has given the value 14,270. As this number corresponds to a very small lowering of the freezing-point, and as the protein is freed from inorganic salts with great difficulty, the result can not be considered trustworthy. It is evident, however, that the molecular weight of proteins is large.

582. When the aqueous solutions of certain proteins are heated the protein separates, and is said to be coagulated. The reaction is irreversible, that is, the coagulated protein can not be brought into solution without subjecting it to the action of reagents which bring about decomposition. The coagulated proteins are obtained as amorphous substances, which dry to a powder and are insoluble in water and solutions of salts. The temperature at which coagulation takes place varies with different proteins. This temperature is affected by the presence of neutral salts in solution, and by the amount of acid or alkali present. Coagulation is complete only in slightly acid solution. The presence of larger quantities of acids or alkalies inhibits coagulation, owing to the conversion of the protein when heated with these substances into metaproteins (the "acid proteins" or "alkali proteins"), which are not coagulated by heat. As it is often difficult to regulate exactly the amount of salt, acid, or alkali present in any given solution of a protein, the temperature at which such a solution coagulates can not be conveniently used as a means of definitely identifying proteins. Under certain conditions, however, these temperatures are definite and their determination is often made use of in studying proteins.

The proteins vary markedly in chemical properties; some are basic and form well characterized salts with active acids, and others are of distinctly acid character. The majority of proteins, however, are neither strongly acidic nor basic, and, consequently, form salts which are readily hydrolyzed by water. They possess an amphoteric reaction, acting as bases towards acids and as acids toward bases.

583. Classification of Proteins. — Although much light has been thrown on the chemical nature of the proteins as the result of the study of their hydrolysis, it is still impossible to classify them on a strictly chemical basis. Much confusion has arisen in the nomenclature of the proteins as the result of the fact that different writers have assigned different meanings to certain terms which have been used in classifying these compounds. The nomenclature which is given below is that adopted by the American Society of Biological Chemists and the American Physiological Society.

I. SIMPLE PROTEINS. Protein substances which yield only α-amino-acids or their derivatives on hydrolysis. The various groups of simple proteins are designated as follows:

(a) *Albumins.* Simple proteins soluble in pure water and coagulated by heat.

(b) *Globulins.* Simple proteins insoluble in pure water, but soluble in neutral solutions of salts of strong bases with strong acids.

(c) *Glutelins.* Simple proteins insoluble in all neutral solvents, but readily soluble in *very* dilute acids and alkalies.

(d) *Alcohol-soluble Proteins, Prolamins.* Simple proteins soluble in relatively strong alcohol (70–80 per cent), but insoluble in water, absolute alcohol, and other neutral solvents.

(e) *Albuminoids.* Simple proteins which possess essentially the same chemical structure as the other proteins, but are characterized by great insolubility in all neutral solvents.

(f) *Histones.* Soluble in water and insoluble in very dilute ammonia and, in the absence of ammonium salts, insoluble even in an excess of ammonia; yield precipitates with solutions of other proteins and a coagulum on heating, which is easily soluble in very dilute acids. On hydrolysis they yield a large number of amino-acids, in which the basic ones predominate.

(g) *Protamines.* Simpler polypeptids than the proteins included in the preceding groups. They are soluble in water, uncoagulated by heat, have the property of precipitating aqueous solutions of other proteins, possess strong basic properties, and form stable salts with strong mineral acids. They yield comparatively few amino-acids, among which the basic amino-acids predominate.

II. CONJUGATED PROTEINS. Substances which contain the protein molecule united to some other molecule or molecules otherwise than as a salt.

(a) *Nucleoproteins.* Compounds of one or more protein molecules with nucleic acid.

(b) *Glycoproteins.* Compounds of the protein molecule with a substance or substances containing a carbohydrate group other than a nucleic acid.

(c) *Phosphoproteins.* Compounds of the protein molecule with some, as yet undefined, phosphorus containing substance other than a nucleic acid or lecithins.

(d) *Hemoglobins.* Compounds of the protein molecule with hematin or some similar substance.

(e) *Lecithoproteins.* Compounds of the protein molecule with lecithins (lecithans, phosphatids).

III. DERIVED PROTEINS.

1. *Primary Protein Derivatives.* Derivatives of the protein molecule apparently formed through hydrolytic changes which involve only slight alterations of the protein molecule.

(a) *Proteans.* Insoluble products which apparently result from the incipient action of water, very dilute acids, or enzymes.

(b) *Metaproteins.* Products of the further action of acids and alkalies whereby the molecule is so far altered as to form products soluble in very weak acids and alkalies, but insoluble in neutral fluids. This group includes what are ordinarily called acid albuminates and alkali albuminates, but does not include the salts of proteins with acids.

(c) *Coagulated Proteins.* Insoluble products which result from the action of heat on their solutions, or the action of alcohols on the proteins.

2. *Secondary Protein Derivatives.* Products of the further hydrolytic cleavage of the protein molecule.

(a) *Proteoses.* Soluble in water, uncoagulated by heat, and precipitated by saturating their solutions with ammonium sulphate or zinc sulphate.

(b) *Peptones.* Soluble in water, uncoagulated by heat, but not precipitated by saturating their solutions with ammonium sulphate.

(c) *Peptids.* Definitely characterized combinations of two or more amino-acids, the carboxyl group of one being united with the amino group of the other with the elimination of a molecule of water.

584. Hydrolysis of Proteins. — The recent advances which have been made in the knowledge of the chemistry of proteins, have been the result of the study of the products formed in the hydrolysis of these highly complicated compounds. The proteins are hydrolyzed when heated with concentrated hydrochloric acid or with strong (about 25 per cent) sulphuric acid. The hydrolysis is also effected by certain enzymes which occur in plants and animals. The products obtained from the simple proteins are amino-acids, the separation of which is attended with considerable difficulty. The method devised by Emil Fischer has proved most generally applicable. It consists, in the main, in converting the acids into esters, and subjecting the latter to fractional distillation under diminished pressure. The method yields only roughly quantitative results, as by its use it is possible to obtain a knowledge of but about 70 per cent of the total products resulting from hydrolysis.

A large number of amino-acids are obtained from most proteins. The names and formulas of those which have been identified, and the structure of which has been established, are given below.

Monamino-monocarboxylic Acids.

Glycine, amino-acetic acid, $CH_2NH_2.COOH$.

Alanine, α-aminoproprionic acid, $CH_3.CHNH_2.COOH$.

Serine, β-hydroxy-α-aminopropionic acid, $CH_2OH.CHNH_2.COOH$.

Phenylalanine, β-phenyl-α-aminopropionic acid, $C_6H_5CH_2.CH_2NH_2.COOH$.

Tyrosine, β-parahydroxyphenyl-α-aminopropionic acid, $HO.C_6H_4.CH_2\text{-}NH_2.COOH$.

Cystine, di-(β-thio-α-aminopropionic acid), $HOOC.CHNH_2.CH_2S-SCH_2.CHNH_2.COOH$.

Valine, α-amino-isovalerianic acid $(CH)_3CH.CHNH_2.COOH$.

Leucine, α-amino-isocaproic acid $(CH_2)_2CH.CH_2.CHNH_2.COOH$.

Isoleucine, α-amino-β-methyl-valerianic acid, $CH_3.CH_2.CH(CH_3).CHNH_2.COOH$.

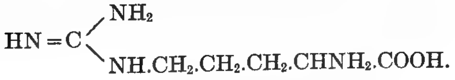
Monamino-dicarboxylic Acids.

Aspartic acid, aminosuccinic acid, $HOOC.CH_2.CHNH_2.COOH$.

Glutamic acid, α-aminoglutaric acid, $HOOC.CH_2.CH_2.CHNH_2.COOH$.

Diamino-monocarboxylic Acids.

Arginine, α-amino-δ-guanidinevalerianic acid,

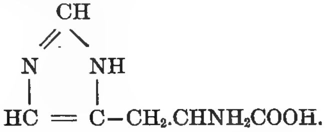


$$HN=C\begin{cases}NH_2\\ NH.CH_2.CH_2.CH_2.CHNH_2.COOH.\end{cases}$$

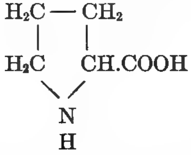
Lysine, α-ε-diaminocaproic acid,
$H_2NCH_2.CH_2.CH_2.CH_2.CHNH_2.COOH$.

HETEROCYCLIC COMPOUNDS.

Histidine, β-imidazole-α-aminopropionic acid,

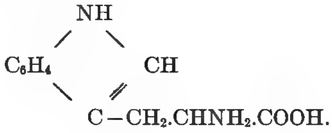


Proline, α-pyrrolidine carboxylic acid,



Hydroxyproline, the mono-hydroxy derivative of proline.

Tryptophane, β-indole-α-aminopropionic acid,



This long list of acids, many of which are formed when a single protein is hydrolyzed, is evidence of the great complexity of the protein molecule.

585. Much work has been done on the determination of the relative amounts of the various acids formed on the hydrolysis of proteins. The methods of separating the complex mixture of acids into its constituents, are but approximately quantitative, and it has been found impossible, up to the present, to isolate the acids in such a way that the amount obtained is equivalent to the weight of protein used. Important results have been obtained, however. In the table which follows, the results of the determination of the amino-acids formed on the hydrolysis of certain typical proteins are given. The numbers express the percentage of the various constituents isolated on hydrolysis. A study of the figures given on the next page, together with the percentage composition of the proteins listed (**581**), leads to some interesting conclusions. While the simple proteins do not differ greatly in chemical composition and yield the same amino acids on hydrolysis, they are made up of these acids in widely different proportions. Although the proteins differ from one another in this respect, it is at present impossible to classify them according to the differences in composition which they show on hydrolysis; the physical properties of the simple proteins are, accordingly, the basis of their classification. Proteins which belong to the same class often resemble one another closely in chemical composition. The vegetable proteins, such as gliadin and zein, yield a large proportion of glutamic acid on hydrolysis. The keratins, which are the chief constituents of hair, nails, horn, hoofs, etc., are characterized by the high percentage of cystine which they contain. The composition of gelatin should be noted; it yields a high percentage of glycine, but no tyrosine, tryptophane, or cystine.

COMPOSITION OF TYPICAL PROTEINS

	Egg-albumin	Serum-albumin	Serum-globulin	Gelatin	Keratin Ox Horn	Gliadin Wheat	Legumin Pea	Zein Maize	Casein Cow's Milk
Glycine	0.	0.	3.5	16.5	0.4	0.02	0.38	0.0	0.
Alanine	2.1	2.7	2.2	0.8	1.2	2.00	2.08	2.23	0.9
Valine	—	—	+	1.0	5.7	0.21	—	0.29	1.0
Leucine	6.1	20.0	18.7	2.1	18.3	5.61	8.00	18.60	10.5
Phenylalanine	4.4	3.1	3.8	0.4	3.0	2.35	3.75	4.87	3.2
Tyrosine	1.1	2.1	2.5	0.	4.6	1.20	1.55	3.55	4.5
Serine	—	0.6	—	0.4	0.7	0.13	0.53	0.57	0.23
Cystine	0.3	2.5	0.7	—	6.8	0.45	—	—	0.06
Proline	2.3	1.0	2.8	5.2	3.6	7.06	3.22	6.53	3.1
Hydroxyproline	—	—	—	3.0	—	—	—	—	0.25
Aspartic Acid	1.5	3.1	2.5	0.6	2.5	0.58	5.30	1.41	1.2
Glutamic Acid	8.0	7.7	8.5	0.9	3.0	37.33	13.80	18.28	11.0
Tryptophane	+	+	+	0.	—	+	+	0.0	1.5
Arginine	—	—	—	7.6	2.3	3.16	10.12	1.16	4.84
Lysine	—	—	—	2.8	—	0.	4.29	0.0	5.80
Histidine	—	—	—	0.4	—	0.61	2.42	0.43	2.59
Ammonia	—	—	—	0.4	—	5.11	1.99	3.61	1.6

586. Qualitative Reactions of Proteins. — All proteins are built up in the same general way from simple molecules, and show, therefore, similar reactions with a large number of reagents. No one of these reactions is characteristic for proteins, but if a substance gives several of them it may be safely considered as a member of this class. Some of these tests are briefly described below.

Proteins may be precipitated from solutions by the following reagents:

I. *Various Mineral Acids.* — Nitric acid is often used. If the acid is allowed to flow into a protein solution a white ring forms at the junction of the acid and the solution. This reaction, which is known as Heller's test, is a very delicate one, and is used in detecting albumin in urine. Peptones are not precipitated by nitric acid.

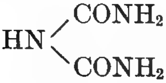
II. *A Mixture of Potassium Ferrocyanide and Acetic Acid.* — The precipitation is produced as the result of the formation of hydroferrocyanic acid, which forms an insoluble compound with the protein. The reaction is used clinically as a test for albumin. Hydroferrocyanic acid gives but a faint precipitate with gelatin, and does not precipitate peptones.

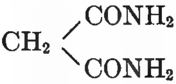
III. *The Ordinary Alkaloidal Reagents.* — The reagents which precipitate alkaloids from their solutions react also with proteins. Among these may be mentioned phosphotungstic acid, phosphomolybdic acid, tannic acid, picric acid, potassium mercuric iodide, and potassium bismuth iodide. The alkaloidal reagents precipitate the majority of the proteins in acid solution only. Tannic acid, phosphomolybdic acid, and phosphotungstic acid precipitate peptones. Most of the acid aniline dyes and many of the organic color bases also precipitate proteins.

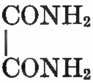
IV. *The Salts of the Heavy Metals.* — Most proteins are precipitated by the salts of heavy metals as insoluble metallic compounds from acid, neutral, or alkaline solutions. Copper acetate, mercuric chloride, and lead acetate are commonly used for this purpose.

587. Some of the more important color reactions of the proteins are given below. All these reactions are not shown by every protein, as the colors produced are due to the presence of certain specific groups, which may or may not be present in a particular protein. Every protein will give, however, a positive reaction in a large number of the tests.

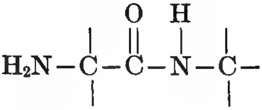
I. *Biuret Reaction.* — When a protein is treated with a solution of sodium hydroxide, and a dilute solution of copper sulphate is added drop by drop, a reddish violet to violet-blue color is produced. The peptones give a red coloration in this test. The test is known as the biuret reaction as it is shown by biuret (**181**). The formation of color appears to be associated with the presence in a molecule of any one of the following groups:







$$\begin{array}{c}CONH_2\\ |\\ CONH_2\end{array}$$



$$H_2N-\underset{|}{\overset{|}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{N}}-\underset{|}{\overset{|}{C}}-$$

II. *Xanthoproteic Reaction.* — When proteins are treated with strong nitric acid a yellow coloration or yellow solid is formed. It is sometimes necessary to heat the solution to boiling to get a positive test. If an excess of sodium hydroxide is added to the solution, the yellow substance formed by the acid is changed in color to orange. The production of the color in this test is probably associated with the presence of a benzene ring in the compound. When many simple derivatives of benzene are treated with strong nitric acid, the nitro-substitution-products formed have a yellow color.

III. *Millon's Reaction.* — The reagent for this test is a solution of mercury in nitric acid containing nitrous acid. When the reagent is added to a solution or suspension of the protein in water, there is obtained either in the cold, or after boiling, a pink coloration of the fluid, or a pink to brownish red coloration of the precipitated protein. The reaction is given by all derivatives of benzene in which one of the hydrogen atoms has been replaced by a hydroxyl group. It thus serves as a delicate test for the presence of tyrosine in a protein.

IV. *Molisch Reaction.* — The test is the same as that applied to carbohydrates (**313**), and when positive in the case of a protein shows the presence in the latter of a carbohydrate. The test is applied by adding concentrated sulphuric acid to a solution of a protein containing a few drops of an alcoholic solution of α-naphthol. A violet color is produced, which turns yellow on the addition of alcohol, ether, or sodium hydroxide. If thymol is used instead of α-naphthol, a carmine-red color is produced, which changes to green on the addition of water.

V. *Sulphur Reaction.* — When a protein solution is warmed with a solution which contains sodium hydroxide and a lead salt, either a black precipitate or brown coloration is produced. The reaction depends on the splitting off of sulphur from cystine, and the subsequent formation of lead sulphide.

VI. *Color Reactions Due to the Presence of the Trytophane Group.* — (*a*) The reaction of Adamkiewiez is carried out by treating a protein solution with one volume of concentrated sulphuric acid and two volumes of glacial acetic acid. A reddish violet color is produced. (*b*) Hopkins and Cole have shown that the color produced results from a reaction between the protein and glyoxylic acid, which is present in glacial acetic acid. Glyoxylic acid is formed when glacial acetic acid is exposed to oxygen in the sunlight. The test for protein is made by treating the latter with a solution of glyoxylic acid, which can be conveniently prepared by reducing oxalic acid with sodium amalgam.

588. Albumins. — Albumins have been isolated from blood-serum, milk, and certain seeds. A protein obtained from eggs and called egg-albumin is usually considered a member of this class, although it yields a derivative of glucose on hydrolysis, and should, accordingly, be classed as a glycoprotein. Albumins are soluble in pure water and form solutions which are neutral and are coagulated by heat. They are not precipitated when their solutions are saturated with sodium chloride or magnesium sulphate.

Serum-albumins occur in the lymph and blood-serum of vertebrates. A crystalline and an amorphous variety have been obtained from blood; the mixture coagulates at 70°–85°. An analysis of serum-albumin is given in section **581**, and the products of hydrolysis in section **585**. *Lact-albumin* is found in all kinds of milk, but is present in relatively small amounts. Cow's milk contains from 0.35 to 0.50 per cent of albumin, which coagulates at 72°–84°, the temperature depending on the concentration and the amount of salts present. *Egg-albumin* forms the chief constituent of white of egg, which also contains a globulin and a mucoid (a glycoprotein). It is probable that there are two albumins in egg-white, one of which has been obtained in crystalline condition. An analysis of egg-albumin is given in section **581**, and a list of the products of hydrolysis in section **585**. In addition to those given, glucosamine, $CH_2OH.(CHOH)_3.CHNH_2.CHO$, is obtained to the extent of 10–11 per cent. Egg-albumin coagulates at about 60°. Among the vegetable albumins are *leucosin*, which is found in the seeds of wheat, rye, and barley, and *legumelin* which has been isolated from peas, lentils, and soy-beans.

589. Globulins. — The globulins are simple proteins which differ from albumins in being insoluble in water and in dilute acids; they dissolve, however, in dilute alkalies and in solutions of neutral salts. They are precipitated by diluting their salt solutions with water, by removing the salts by dialysis or by the addition of acids; they are salted out completely by magnesium sulphate. Globulins have been isolated from blood-serum, certain organs, the crystalline lens, eggs, milk, seeds, and other sources. *Fibrinogen,* which shows the general characteristics of the globulins, occurs in the blood-plasma of all vertebrates. The fluid portion of the blood before coagulation takes place, is called plasma. As soon as blood leaves the arteries, the so-called fibrin enzyme converts the fibrinogen into *fibrin,* the change bringing about the clotting of the blood. The solution obtained after the removal of fibrin is called serum. The coagulation-temperature of fibrinogen is given as 56°. Blood plasma contains about 0.4 per cent of this protein.

Sarcoplasma, the fluid contents of the sarcolemma-sheaths of striped muscle, contains proteins from which have been isolated *myosin* (also called *musculin* or *paramysinogen*) and *myogen* (or *mysinogen*). Myosin possesses the essential properties of the globulins. It is readily salted out by sodium chloride. If kept in solution for some time it passes into an insoluble form which resembles fibrin. The coagulation of myosin which takes place after death gives rise to what is known as *rigor mortis.* Myogen constitutes about 80 per cent of the muscle-protein. It is fairly soluble in water, has a neutral reaction, and is readily converted into a metaprotein by acids.

590. Glutelins and Prolamins. — Cereals contain in addition to albumins and globulins glutelins, and the so-called alcohol-soluble proteins (*prolamins*). *Gluten*, the adhesive glue-like material present in wheat, which gives to dough its toughness, is considered to be a mixture of two proteins. One, called *glutenin*, is a glutelin, which is insoluble in alcohol, water, or salt solutions; the other called *gliadin*, is soluble in a mixture of water and alcohol. The alcohol-soluble proteins of seeds are characterized by yielding on hydrolysis no lysine and a high percentage of glutamic acid. The products formed from gliadin and zein are tabulated in section **585**.

591. Albuminoids. — The proteins which are characterized by great insolubility in neutral solvents are classed as albuminoids. To this group belong the proteins which constitute the framework of the animal tissues and those which are important constituents of the animal skeleton or cutaneous structure.

Collagen constitutes the fibrils of connective tissue and the foundation of bone and cartilage. When collagen is treated with tannic acid it shrinks greatly, hardens, and a substance is formed which does not putrefy; the use of tannin in the preparation of leather is based upon these facts. When collagen is boiled with water it is converted by partial hydrolysis into what is called *gelatin* or *glue*, which passes into solution; on cooling, the gelatin solidifies to a jelly, which redissolves on heating. When gelatin is boiled with water or with dilute solutions of acids or alkalies, the hydrolysis proceeds further; gelatoses, which do not possess the property of gelatinizing, are formed. The final products of hydrolysis are amino-acids. This change is also brought about by peptic and tryptic digestion. The products of hydrolysis of gelatin are listed in section **585**; the high percentage of glycine formed and the absence of tryosine, cystine, and tryptophane are noteworthy.

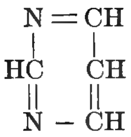
The *keratins* are the chief constituents of the epidermis and the horny substance found in mammals and birds; they occur in hair, hoofs, horns, and feathers, and are the most insoluble of all the albuminoids. The products of the hydrolysis of the keratin obtained from the horn of the ox are enumerated in section **585**. In addition to those given, ammonia is obtained in relatively large amounts. The keratins contain a relatively high percentage of cystine; human hair yields about 14 per cent of this acid. With nitric acid the keratins give a marked xanthoproteic reaction which is observed, for example, when the acid comes in contact with the skin.

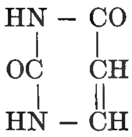
Elastin constitutes the yellow elastic fibers in ligaments, and the outer wall of arteries. It is not affected by dilute acids or alkalies in the cold, but is digested by pepsin and hydrochloric acid. It yields 25 per cent of glycine and 21 per cent of leucine on hydrolysis. *Fibroin*, which is the chief constituent of the fibers of silk, differs markedly from the other albuminoids and albumins in composition. It contains about 19 per cent of nitrogen, and yields on hydrolysis 36 per cent of glycine, 21 per cent alanine, and 10 per cent tyrosine.

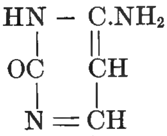
592. Histones are characterized by their basic character; they yield a high percentage of arginine and lysine on hydrolysis. They are soluble in water, and are precipitated on the addition of ammonia. The protein constituent of hemoglobin, the red coloring matter of the blood, is classed as a histone; it is called *globin*.

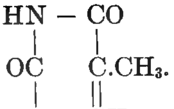
593. Nucleoproteins are composed of simple proteins, generally protamins, histones, or albumins, and a nucleic acid. They are the chief constituents of the cell nuclei, and in those organs especially rich in cells, such as the thymus and the lymph glands, exceed in quantity all other proteins. Nucleoproteins have been isolated from the spermatozoa of fish, the thymus, the pancreas, the thyroid, the liver, muscle, yeast, bacteria, and from certain plants. It is probable that the nucleoproteins play an important part in the building up of the cell-plasm from the products formed as the result of the hydrolysis of the protein constituents of foods.

594. The nucleic acids obtained from nucleoproteins are of unknown constitution, but their dissociation-products are fairly well known. They yield on hydrolysis phosphoric acid, pentoses, and derivatives of pyrimidine and of purine (**338**). It is beyond the scope of this book to discuss adequately the structure of the derivatives of pyrimidine and purine which are obtained from the nucleic acids. The graphic formulas of the derivatives which have been isolated are given here for reference. Uracil, cytosine, and thymine are derivatives of pyrimidine: —

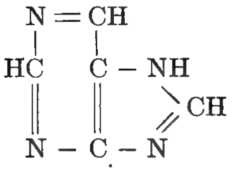

pyrimidine

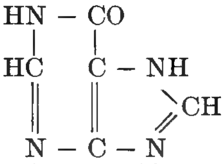

uracil

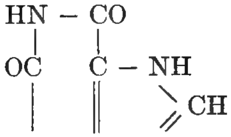

cytosine

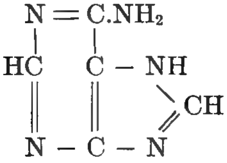

thymine

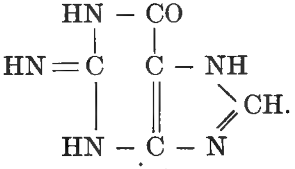
Hypoxanthine, xanthine, adenine, and guanine are derivatives of purine: —


purine


hypoxanthine


xanthine


adenine


guanine

Recent work shows that in certain nucleic acids the phosphoric acid is joined to the pentose molecule, which, in turn, is linked to the pyrimidine or purine derivative.

595. Glycoproteins are characterized by yielding on hydrolysis a carbohydrate or a derivative of a carbohydrate, such as glucosamine. To this group belong the mucins, mucoids, and, perhaps, egg-albumin. The glycoproteins, as a class, are difficultly soluble in water, are acids, and are uncoagulated by heat. *Mucins* form more or less adhesive solutions and are found in most of the slimy fluids occurring in the body. The mucin of saliva is salted out by sodium chloride or magnesium sulphate solutions and is precipitated by acetic acid. The *mucoids* differ from the mucins in not being precipitated by acids. They are found in blood-serum, in the white of egg, and along with collagen in the tissues.

596. Phosphoproteins. — Proteins of this class when subjected to the action of pepsin and hydrochloric acid, undergo hydrolysis, and yield proteoses and an acid containing phosphorus, which is called paranucleic acid. This acid is sharply distinguished from the nucleic acids, as neither xanthine bases, pyrimidine derivatives, nor pentoses occur among its dissociation-products. Paranucleic acid has not been obtained in the pure condition, and its decomposition-products are not definitely known. The phosphoproteins are distinctly acid, are insoluble in water, and form soluble salts which contain the alkali metals and ammonium.

Casein which is a phosphoprotein, is the chief nitrogenous constituent of milk, in which it occurs as a calcium salt in combination with calcium phosphate. Casein is insoluble in water, but its salts are readily soluble; those of calcium, barium, strontium, and magnesium form opalescent colloidal solutions. The sodium, potassium, and ammonium salts form comparatively clear solutions, which pass through clay filters. Casein also forms salts with acids. It is precipitated from a solution of its salts and from milk by small quantities of mineral acids, and by larger amounts of acetic acid, but it dissolves in an excess of acid. Casein and its salts are precipitated from solutions by saturating the latter with sodium chloride, magnesium sulphate, or sodium sulphate. The solutions of the salts of casein may be boiled without undergoing coagulation. When heated in the dry condition at from 94° to 100°, casein becomes partly insoluble. The products of the hydrolysis of casein are listed in section **585**.

The casein in milk is coagulated in the presence of calcium salts by rennin, an enzyme found in rennet, which is made from the mucous membrane of the stomach of the calf. The product formed is called *paracasein;*[1] it resembles casein in being soluble in alkalies, but its calcium salt is insoluble. The coagulation produced by rennin results, therefore, in the conversion of the soluble calcium salt of casein into the insoluble calcium salt of paracasein. If milk is treated with an oxalate and the calcium precipitated as calcium oxalate, the casein left in solution is not coagulated by rennin. In all other properties paracasein is like casein, except that it is precipitated more easily by sodium chloride. The caseins obtained from various sources resemble one another closely. That obtained from human milk, however, gives a pronounced carbohydrate reaction when tested with the Molisch reagent, while the casein from cow's milk gives but a very faint reaction.

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[1] There is confusion in the naming of the proteins which are called here by the names usually given to them, viz., casein and paracasein. Some authors designate these substances by the more logical names caseinogen and casein, respectively.

Vitellin is a protein which contains phosphorus, and yields a paranucleic acid on hydrolysis. It has been obtained from the yolk of hen's eggs. Its coagulation-temperature is given as 75°.

597. Hemoglobins. — The conjugated proteins of this class occur in the red coloring matter of the blood of vertebrates and invertebrates. The red corpuscles of mammals are composed largely of hemoglobin. The dried red blood corpuscles in man contain 94.3 per cent and those in the dog 86.5 per cent of this protein. Hemoglobin is composed of a basic protein, called *globin,* which resembles the histones in character, and *hematin,* a substance which contains iron and is not a protein. It is probable that hemoglobins from different sources differ in composition, but the essential constituent which contains iron is the same in all. Hemoglobin combines directly with oxygen, carbon monoxide, and other compounds to form substances which readily undergo decomposition. This power of hemoglobin to form a loose compound with oxygen is of vital importance in animal physiology. Hemoglobin is the carrier of oxygen to all the tissues. Oxyhemoglobin can be obtained readily in the crystalline form. When treated with acids or alkalies hemoglobin is converted into globin and hematin. Hematin is obtained as a non-crystalline bluish-black powder, which is insoluble in water but soluble in alkaline solutions. Hydrochloric acid converts hematin into hemin, a substance which crystallizes in characteristic microscopic chocolate-colored plates. This reaction forms the basis of a very delicate method of detecting blood-stains. The change of hematin to hemin appears to consist in the replacement of a hydroxyl group by chlorine. The equation written for the reaction is,

$$C_{34}H_{34}N_4FeO_5 + HCl = C_{34}H_{33}N_4FeO_4Cl + H_2O$$

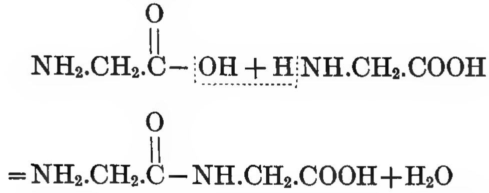
although there is still some doubt as to the exact chemical composition of the iron compounds. Hematin has been shown to be a derivative of pyrrole.

598. Derived Proteins. — A few primary protein derivatives have been mentioned in connection with the substances described above. Paracasein and fibrin are formed as the result of the action of certain enzymes on casein and fibrinogen, respectively. The metaproteins are obtained by treating proteins with dilute acids or alkalies. Acids form acid-proteins, which are soluble in acids and insoluble in alkalies. The latter form soluble alkali-proteins, which are precipitated by acids. Many soluble proteins are changed into insoluble substances (coagulated) when heated. The derived proteins resemble closely the substances from which they are formed except in solubility. The nature of the change is not understood. It is possible that the conversion of a protein into a primary derivative may be associated with a change in the colloidal condition of the molecule.

The secondary protein derivatives result from hydrolytic cleavage. As proteins yield a large number of amino-acids on complete hydrolysis, it is evident that they are built up by the combination of these acids as the result of the elimination of water. When a molecule so constituted is cautiously hydrolyzed, it is conceivable that hydrolysis may take place in stages, that is, it may yield two, three, four, etc., parts which, on further hydrolysis, may break into simpler molecules. The final stage is that which yields the simple amino-acids. An examination of the products formed as the result of the partial hydrolysis of proteins leads to accepting this view as correct. The products of hydrolysis are mixtures, and the classification adopted for them is, therefore, arbitrary. As hydrolysis of a protein proceeds, the substances first obtained are soluble in water, not coagulable by heat, and are precipitated by saturating their solutions with ammonium sulphate. These are called proteoses. Albumins yield albumoses, globulins yield globuloses, and so forth. Continued hydrolysis results in a further cleavage of the molecule, and the resulting products, called peptones, are not precipitated by ammonium sulphate. During the entire process of hydrolysis amino-acids are formed along with the proteoses and peptones. The peptones on further hydrolysis are converted into peptids, and finally into amino-acids. Peptids are compounds formed as the result of the condensation of two or more molecules of amino-acids, with the elimination of water. The structure of a number of peptids obtained by the hydrolysis of proteins has been established as the result of their synthesis from acids of known constitution. It is probable that the simple proteins and their more complex cleavage-products are polypeptids, or mixtures of polypeptids, which are compounds formed as the result of the condensation of a number of amino-acids. The term peptid in the system of nomenclature which has been given (**583**) is reserved for definitely characterized compounds of this type.

Hydrolysis of proteins is effected by acids, bases, and certain enzymes. The extent to which the cleavage takes place is determined, in the case of acids, by their concentration, the temperature, and the length of time during which the action is allowed to take place. In the case of enzymes, the results are determined by the nature of the enyzme. Pepsin, which is present in the gastric juice, and trypsin, the enzyme of the pancreatic fluid, have been much studied. Pepsin in the presence of hydrochloric acid converts proteins into peptones; trypsin brings about hydrolysis to amino-acids.

599. Structure of Proteins: Peptids. — Much light has been thrown recently on this problem as the result of the work of Emil Fischer on the peptids. A number of hypotheses have been put forward as to the way in which the amino-acids obtained from proteins are linked to one another in the molecule. It is possible that the linking may be brought about through the direct union of carbon atoms, but this view seems improbable in the light of the fact that proteins are readily decomposed by hydrolysis. The amino-acids obtained from proteins contain few hydroxyl groups other than those in the carboxyl group. This fact excludes the possibility that the linking is effected to any great extent through oxygen atoms. From the structure of the peptids, some of which have been obtained from natural sources, it is evident that nitrogen is the element that serves, in large measure, to hold together the parts of which the molecule is composed. The manner in which combination is effected is that shown in the following equation, which illustrates the union of two molecules of glycine: —



$$NH_2.CH_2.\overset{\overset{O}{\|}}{C}-OH + H NH.CH_2.COOH$$

$$= NH_2.CH_2.\overset{\overset{O}{\|}}{C}-NH.CH_2.COOH + H_2O$$

The nature of the union is similar to that in an amide: —

$$CH_3CO\,OH + H\,NH_2 = CH_3CO.NH_2 + H_2O$$

The product formed as the result of the condensation of two molecules of glycine is called glycyl-glycine. According to the structure assigned to it, it is a substitution-product of the amide of amino-acetic acid, $NH_2CH_2CO.NH_2$, in which one hydrogen atom is replaced by the group $CH_2.COOH$. Many facts are in accord with this view of the amide-like nature of the linking of amino-acids in proteins. The proteins are hydrolyzed under the conditions used to effect the hydrolysis of amides. When proteins are treated with nitrous acid only a small amount of nitrogen is set free, a fact which shows that the protein molecule contains but a small proportion of its nitrogen as amino groups. It will be recalled that when a substance which contains this group, such as CH_3NH_2, is treated with nitrous acid the nitrogen present is set free, and the amino group is replaced by hydroxyl. The fact that proteins give the biuret reaction is further evidence that the molecules of amino-acids of which they are built up are joined together in the way indicated. A study of the structure of the substances which give this reaction has shown that such compounds contain two CO — NH, two CS — NH, or two C(NH) — NH complexes, combined directly or by a carbon or nitrogen atom. Such a method of linking as that indicated above in the case of glycine, takes place in the living body. It has been shown that if benzoic acid, $C_6H_5.COOH$, and glycine, NH_2CH_2COOH, are taken into the system, they are excreted as hippuric acid, $C_6H_5CO.NH.CH_2COOH$. The acids found in the bile are compounds of this nature.

600. A number of methods have been devised to effect the union of amino-acids in the manner which has been described, and to prepare compounds which have the structure resulting from such union. It is beyond the scope of this book to describe these methods in detail; only two of the more important methods used by Fischer will be mentioned briefly. It will be recalled that amides are prepared by treating acid chlorides with ammonia: —

$$CH_3COCl+2NH_3=CH_3CO.NH_2+NH_4Cl$$

Acyl chlorides react also with substitution-products of ammonia:

$$CH_3COCl+NH_2.CH_2COOH=CH_3CO.NH.CH_2COOH+HCl.$$

Up to the time when the work on the peptids was undertaken it was impossible to prepare the chlorides of the amino-acids. Fischer, however, succeeded in making these compounds, as well as the chlorides of the peptids, by treating the acids with phosphorus pentachloride in the presence of acetyl chloride. The chlorides thus prepared condensed readily with amino-acids, or with peptids. In this way, for example, alanyl-glycine was prepared: —

$$CH_3.CH(NH_2).COCl+NH_2.CH_2.COOH=$$
$$CH_3.CH(NH_2).CO.NH.CH_2.COOH+HCl$$

This compound is a dipeptid. A tripeptid can be synthesized by converting a dipeptid into an acyl chloride, and condensing the latter with an amino-acid. Leucyl-glycyl-glycine was prepared in this way. Leucyl-glycine was first formed from leucyl chloride and glycine, and, after conversion into a chloride, was condensed with glycine: —

$$(CH_3)_2CH.CH_2.CH(NH_2).CO.NHCH_2.COCl + NH_2.CH_2.COOH$$
$$= (CH_3)_2CH.CH_2.CH(NH_2).CO.NHCH_2.CO.NHCH_2.COOH + HCl$$

By continuing the process, molecules of great complexity can be obtained. Fischer prepared an octadecapeptid, which consists of eighteen molecules of amino-acids in combination. Its name is indicative of its structure: leucyl-triglycyl-leucyl-triglycyl-octaglycyl-glycine. This substance has the highest molecular weight of any compound as yet prepared by synthesis, and of which the constitution is known. Its molecular weight is 1213.

Another synthetic method which has been very fruitful is based on the use of the chlorides of halogen-substituted acids. Chloracetyl chloride and α-amino-propionic acid, for example, yield an acid, which is converted by ammonia into a dipeptid. The equation for the first reaction is as follows: —

$$\begin{aligned}&ClCH_2CO.Cl + NH_2CH(CH_3).COOH\\&= ClCH_2CO.NHCH(CH_3).COOH + HCl.\end{aligned}$$

By the action of ammonia the chlorine atom is replaced by the amino group, and glycyl-alanine is formed. By condensing α-brompropionyl chloride with glycine, and subsequent treatment with ammonia, alanyl-glycine is formed: —

$$\begin{aligned}&CH_3.CHBr.COCl + NH_2CH_2.COOH\\&\rightarrow CH_3.CHBr.CO.NHCH_2.COOH\\&\rightarrow CH_3.CH(NH_2).CO.NHCH_2.COOH.\end{aligned}$$

It is thus possible by this method of synthesis to prepare peptids in which the acid radicals are joined in any desired order. Glycyl-alanine and alanyl-glycine are both made up of glycine and alanine, but in the former compound the carboxyl group is in the alanine residue, while in the latter it is in the glycine residue. A great many polypeptids — those containing a number of amino-acids in combination — have been prepared by the method illustrated in the two simple cases given above.

601. The majority of peptids are readily soluble in water and insoluble in alcohol. Those which dissolve with difficulty in water are soluble in acids and in alkalies. Most of the peptids have a bitter taste, and melt above 200° with decomposition. The simpler compounds give no precipitate with phosphotungstic acid, but many tripeptids and most tetrapeptids are precipitated by this reagent. Those which contain eight molecules of amino-acids resemble in solubility the proteins. They are precipitated by phosphotungstic acid and tannic acid, and are salted out by ammonium sulphate. Many tripeptids give the biuret reaction. The color produced when this test is applied to the peptids increases in intensity with increase in complexity of the molecule.

602. The behavior of the peptids when submitted to the action of hydrolytic agents, is markedly similar to that of the proteins. The peptids are completely hydrolyzed to amino-acids when heated with concentrated hydrochloric acid for five hours. The action of enzymes on the peptids furnishes a striking proof that some of them resemble the proteins in the manner in which the acids present are held in combination. Pepsin does not effect the hydrolysis of peptids. This fact is explicable, when we remember that this enzyme breaks down proteins into peptones only, and does not yield amino-acids. It is highly probable that the peptones are polypeptids. Certain peptids are hydrolyzed by trypsin, and certain ones are not. As trypsin converts proteins into amino-acids, it is evident that the linking present in the peptids which are unaffected by trypsin is in all probability not involved in the building up of proteins. A study of the hydrolysis of peptids by trypsin and other hydrolytic enzymes has thrown much light on the structure of proteins. The subject is being actively investigated. Glycyl-alanine is not hydrolyzed by trypsin, whereas alanyl-glycine is hydrolyzed. If tyrosine or cystine is situated at the end of a chain in a peptid, they are split off by trypsin. If, on the other hand, they play the part of the acid radical, the molecule is not split at the union between the radical and the amino-acid with which it is in combination. It is evident that such facts as these are of the greatest value in the interpretation of the structure of the protein molecule.

Most of the acids obtained from proteins by hydrolysis are optically active. Fischer has prepared many optically active peptids, and has discovered that the configuration of the molecule is an important factor in its hydrolysis by trypsin. For example, *d*-alanyl-*d*-alanine is hydrolyzed, but *d*-alanyl-*l*-alanine is not. Racemic peptids, that is, those which consist of a mixture of equal parts of dextro and levo compounds, are hydrolyzed asymmetrically, only one form, and that the form which occurs in proteins, being attacked by the enzyme. Up to the present, only those peptids have been hydrolyzed which contain the optically active forms of the amino-acids which result from the hydrolysis of naturally occurring compounds.

By the careful hydrolysis of certain proteins, peptids of definite structure have been obtained. From silk-fibroin have been obtained the anhydrides of glycyl-*d*-alanine and glycyl-*l*-tyrosine, and a tetrapeptid which consists of two molecules of glycine, one molecule of alanine, and one molecule of tyrosine. It has been shown that the products of the partial hydrolysis of elastin contain *d*-alanyl-*l*-leucine, alanyl-proline anhydride, and glycyl-valine anhydride. Other peptids have been obtained from gliadin and casein.

INDEX

(The references are to pages; the more important ones are given in bold face type.)

A

Acetaldehyde, **175–182**, see also aldehyde
Acetals, 180, 288
Acetamide, 194, **206**
Acetanilide, 418, **422**
Acetates, 109
Acetbromamide, 250
Acetdibromamide, 251
Acetic acid, 25, 64, 77, **107**, 108–114, 296, 314, 537
  tests for, 113
Acetic anhydride, 148
Acetoacetic acid, 280
  ester, 280
  ester synthesis, 283
Acetone, 64, 80, **186–188**, 240, 314, 377, 427
Acetone-dicarbonic acid, 276
Acetonitrile, 208
Acetophenone, **473**, 476
  chloride, 381
Acetoxime, 179
Acetylene, 43, 55, **56–60**, 244, 314, 373
  diiodide, 58
  tetrabromide, 58
  tetrachloride, 58
Acids, aromatic, 456
  detection of, 120, 342
  fatty, 103
  ionization constants of, 294–297, 505
  monobasic, 103
  nomenclature of, 116, 121
Aconitic acid, 140
Acrolein, **184**, 310, 314, 534
Acrose, 174, 310
Acrylic acid, **121–123**, 297
  aldehyde, 184, see also acrolein
Acyl chlorides, 67
  halides, 245–248
  radicals, 104
ADAMKIEWIEZ reaction, 552
Addition to double bond, 51
Adenine, 556
Adipic acid, 131
Adonitol, 102
Aesculetin, 306
Aesculin, 306
Agar-agar, 327
Alanine, 293, 547
Alanyl-glycine, 562, **563**
Albumins, 552
Albuminoids, 554
Albumoses, 559
Alcohol, 44, **70–78**, 87, 319
  denatured, 64, 74
  test for, 77
Alcohols, 63
  aromatic, 442
  detection of, 91, 342
  nomenclature of, 86
  oxidation of, 77, 79, 82
  polyatomic, 96, 102
  preparation of, 88
  primary, 80
  secondary, 80, 90
  tertiary, 82, 90
  unsaturated, 94
Aldehyde, 77, **175–182**, 314
  ammonia, 178
  -resin, 180
Aldehydes, 89, 90
  aromatic, 468
  identification of, 183, 344
  nomenclature of, 171
Aldol, 180
Aldoximes, 179
Alicyclic compounds, 524
Aliphatic compounds, 360
Alizarin, 385, **515**
  carmine, 516
  orange, 516
Alkaloidal reagents, 538
Alkaloids, 205, **538**
Alkyl cyanides, 223
  halides, 230
  halides, indentification of, 235
  halides, preparation of, 232

Alkyl halides, reactions of, 234
    isocyanides, 225
    radicals, 104
Allantoine, 357
Allene, 61
Alloxan, 356
Allyl alcohol, 94
    iodide, 100
    isosulphocyanate, 95, 307
    isothiocyanate, 336
    sulphide, 95, 332
Allylene, 60
Almonds, oil of, 469
Aluminium carbide, 24
Amides, 192, 206
    identification of, 214, 345
    structure of, 208
Amido group, 193
Amidol, 489
Amines, aromatic, 416
    fatty, 191, 200
    identification of, 201, 345, 426
    preparation of, 200
    primary aromatic, 417
    reactions of, 201
    secondary aromatic, 419
    tertiary aromatic, 419
    tests for, 403
Amino group, 193
    -acetic acid, see glycine
    -acids, 290–292
    -azo compounds, 435
    -azobenzene, *p*–, 435, 436
    -benzenesulphonic acid, *p*–, 492
    -benzoic acids, 497
    -benzoylformic acid, *o*–, 529
    -formic acid, 290
    -naphthalene, 384
    -phenol, *p*–, 478
    -phenols, 488
    -propionic acid, α-, see alanine
Ammonium carbamate, 212
    cyanate, 210
    thiocyanate, 335
Amygdalin, 306
Amyl, see also isoamyl
    alcohol, 71
    alcohol (active), 294
    alcohols, 83
    bromide, 230
    chloride, 230
    iodide, 230
Amylene, 51
Amyloid, 324
Analysis, qualitative, 10
    quantitative, 11, 12
Anhydrides, identification of, 151, 345
Anhydrogeraniol, 524
Aniline, 314, **420**, 428
    yellow, 513
Anisol, 453
Anthracene, 3, 366, **385**
    oil, 365
Anthranilic acid, 497
Anthragallol, 516
Anthraquinone, 481
Arabin, 327
Arabinose, 313
Arabitol, 102
Arbutin, 450
Arginine, 547
Armstrong, 363
Aromatic compounds, 360
Aryl radicals, 395
Aseptol, 488
Asparagine, 268, **294**
Aspartic acid, 547
Aspirin, 499
Asymmetric carbon, 84
Atropine, 539
Aurin, 520
Auxochrome group, 510
Azelaic acid, 127
Azobenzene, 428, **429**
Azoxybenzene, 428, **429**

B

Baeyer, 363
Baking-powders, 273
Barium carbide, 219
    cyanide, 219
Barley-sugar, 314
Beckmann's rearrangement, **475**
Beer, 73
Beeswax, 166
Benzal chloride, 375, 381, **413**, 462
    -acetone, 476
Benzaldehyde, 413, 443, 459, 462, **469–471**
Benzaldoxime, 472
Benzamide, **460**
Benzene, 41, 43, 59, **360–364**, **373**, 433, 447
    hexachloride, 374
    -diazo hydroxide, 438
    -diazonium hydroxide, 438
    -disulphonic acid, *m*–, 450
    -sulphonamide, 403
    -sulphonic acid, 374, **402**
    -sulphonyl chloride, 403
    -trisulphonic acid, 1, 3, 5–, 451
Benzhydrol, see diphenylcarbinol
Benzidene, 429
Benzil, **476**, 485
Benzine, 41

Benzoic acid, 376, 413, **458**, 506
  aldehyde, see benzaldehyde
  anhydride, 459
Benzoin, 470, 476, **484**
Benzol, 365
Benzo-nitrile, 460
  -phenone, 370, 378, **474**
  -phenone chloride, 381, **413**
  -quinone, see quinone
  -quinone, *o*–, 480
  -trichloride, 375, **413**, 458
Benzoyl chloride, **459**, 471
  hydrogen peroxide, 469
Benzyl alcohol, **442–444**, 470
  chloride, 375, 409, **413**
  -amine, 416, 419, **424**
Betol, 499
Birotation, 301
Bismarck brown, 514
Biuret, 211
  reaction, 550
Blue-print paper, 223
Boiling-points, determination of, 6, 7
  and structure, 88
Borneol, 527
Brandy, 73
Brom-acetanilide, 422
  -acetic acid, 254, 296
  -benzene, 409, **411**, 446
  -benzoic acids, 506
  -ethylene, 58
  -nitrobenzenes, 483
Bromoform, 239
Brom-phenol, *o*–, 483
  -phenols, 487
  -phenylacetic acid, α–, 500
  -prophylene, 1–, 237
  -propionic acid, α–, 255, 256, **258**
  -propylene, 2–, 237
  -propylene, 3–, 238
  -protocatechuic acid, 503
  -succinic acid, 269
Brucine, 541
BUCHNER, 306
BUNSEN, 330
Butane, *n*–, 37, 38, 53
Butanes, **33–34**
Butine, 60
Butter, 164, 165
  yellow, 514
Butyl, see also isobutyl
  alcohol, *n*–, 87
  alcohols, 82, 88
  bromide, 230
  bromide, *sec*–, 232
  bromide, *ter*–, 232
  chloride, 230
  chloride, *sec*–, 232
Butyl, chloride, *ter*–, 232
  halides, 232
  iodide, 230
  iodide, *sec*–, 232
  iodide, *ter*–, 232
  -amine, 200
Butylenes, **50**, 51, 53
Butyric acids, 115, **117**, 296

C

Cacodyl, 330
Cadaverine, **205**, 294
Caffeine, 359
Caffetannic acid, 504
Caffetannin, 504
Calcium butyrate, **117**
  carbide, 57
  cyanamide, 218
  oxalate, 135
  sucrates, 315
Camphene, 525
Camphor, 376, **526**
Camphoric acid, 527
Candles, 118
Cane sugar, see sucrose
Capric acid, **115**, 165
Caproic acid, **115**, 165
Caprylic acid, 115
Caramel, 314
Caraway, oil of, 377, 472, 525
Carbamic acid, 211
Carbohydrate, definition of, 299
Carbohydrates, formation of, 174
  identification of, 327
Carbolic acid, 365, 448
Carbon monoxide, 64, 133
  tetrabromide, 239
  tetrachloride, 239, 242
Carbonium compounds, 415
Carbonyl chloride, 241, **248**
Carboxyl group, 25, 104
Carbylamine reaction, 197, **226**
Carnauba wax, 166
Carriers, halogen, 254, 374
Carvacrol, 448
Casein, 318, 544, 549, **557**
Catechol, see pyrocatechol
Celluloid, 325
Cellulose, **323–326**
  acetate, 325
  nitrate, 325
  xanthate, 336
Cerotic acid, 166
Cetyl alcohol, **87**, 166
  palmitate, 166
Champagne, 73
Charcoal, 64

Checkerberries, 63
Cheese, 318
Cherry-laurel, oil of, 442
Chloracetic acid, 220, 254, **258**, 296
Chloracetone, 289
Chloral, 287
  alcoholate, 288
  hydrate, 288
Chloramylamine, ε–, 533
Chloranil, 479
Chlor-benzene, 409, 446
  -benzenesulphonic acid, *p*–, 450
  -benzoic acids, 506
  -carbonic ester, 249
Chloroform, 196, 239, **240**, 491
Chlor-toluene, *o*–, 376
  -toluene, *p*–, 376
  -toluenes, 412
Cholesterol, 165
Choline, 204
Chromophore group, 509
Chrysolin, 523
Cineol, 527
Cinnamic acid, 380, 445, **461**, 506
  aldehyde, 445, **472**
Cinnamyl alcohol, 445
Citral, 185
Citric acid, 275–277
Claisen, 280
Claus, 363
Cloves, oil of, 489
Coal-gas, 56
  -tar, 365
Cocaine, 540
Cod-liver oil, 165
Coffee, 359
Collagen, 554
Collidines, 534
Collodion, 325
Colophony, 525
Color-bases, 518
Condensation, 181
Congo red, 514
Coniferin, 492
Coniferyl alcohol, 492
Coniine, 539
Copper acetylide, 59
Cordials, 73
Cordite, 101
Cosmetics, 99
Cotton, mercerized, 324
  -seed oil, 164, 165
Coumarin, 529
Cracking of petroleum, 42
Cream of tartar, 272
Creasote oil, 365
Creatine, 293
Creatinine, 293
Cresols, 365, 448
Crotonic acids, **124–126**, 297
Crystal violet, 519
Crystallization, 7, 8
Cuminic aldehyde, 472
Cyan-acetic acid, 220, 296
  -amide, 218
Cyanic acid, 218, 228
Cyanides, alkyl, 223
Cyanogen, 216
  chloride, 217
Cyanuric acid, 229
  chloride, 229
Cyclo-hexadiene, 389
  -hexane, 388
  -hexene, 368, **389**
Cymene, **376**, 524, 526
Cymogen, 41
Cystine, 547, 556

D

Decane, 37
Decyl alcohol, 87
Decylene, 51
Desoxybenzoin, 476, 485
Developers, photographic, 489
Dextrin, 322
Dextrose, 71, **300–305**, 312, 318
Diacetamide, 192
Diamines, 205
  aromatic, 420
Diastase, 71, 319, 322, 323
Diazo-acetic ester, 440
  -amino compounds, 434
  -aminobenzene, 434
  compounds, 431
  compounds, aliphatic, 440
  -methane, 440
Diazonium compounds, 432–434
Dibenzalacetone, 476
Dibenzyl, **378**, 485
Dibrom-acetic acid, 278
  -benzenes, 411
  -propane, 1, 1–, 239
  -propane, 1, 3–, 239, 244
  -propane, 2, 2–, 239
  -propionic acid, α, α–, 255
  -propionic acid, α, β–, 259, 266
  -succinic acid, 271
Dibutylamine, 200
Dibutylene, 50
Dichlor-acetic acid, **258**, 296
  -benzophenone chlorides, 414
  -ethane, 32
  -hydrin, 100
  -methane, 29
  -propane, 2, 2–, 243
  -toluene, 2, 4–, 376

Diethyl-amine, 200
-sulphone, 332
Digallic acid, 503
Dihydro-anthracene, 482
-benzene, 389
-pyrrole, 529
Dihydroxyacetone, 312
Di-iodoform, 242
Dimethyl-acetylene, 56
-amine, 193, **197**, 200, 426
-amino-azobenzene, *m*–, 435
-aniline, 426
-ethylene, 50
-*p*–phenylenediamine, 436
sulphate, 69
Dinaphthols, 449
Dinitro-benzene, *m*–, 417
-benzenes, 397, 398
-benzoic acids, 495
-brombenzenes, 484
-phenol, 2, 6–, 398
Dioctylamine, 200
Diolefines, 61
Dipentene, 525
Diphenic acid, 387
Diphenyl, 366, **382**
-amine, 419, **425**
-carbinol, 444
-chlormethane, 413
-dichlormethane, 413
-ethane, 378
-ether, 454
-ethylene, 371
-iodonium hydroxide, 412
ketone, see benzophenone
-methane, **377**, 381
-methyl-methane, 378
-phthalid, 521
Dippel's oil, 528
Dipropylamine, 200
Dithiocarbonic acid, 336
Distillation, destructive, 4
Dodecane, 37
Dodecatyl alcohol, 87, 166
Dodecylene, 50
Double bond, 48, 51
Dulcitol, 102
Dyes, 509
adjective, 511
azo, 513
naming of, 512
substantive, 511
triphenylmethane, 516
Dynamite, 101

E

Edestin, 543
Egg albumin, 544, 549, **552**
Eicosane, 37
Eikonogen, 489
Eka-iodoform, 242
Elaidic acid, 128
Elaidin test, 128, 164
Elastin, 555
Electro-reduction of nitro compounds, 428
Enzymes, 306
Eosin, 523
Erythric acid, 266
Erythritol, 102
Erythrose, 313
Ester, 77
Esterification, law of, 495
Esters, identification of, 167, 344
preparation of, 159
ÉTARD synthesis, 469
Ethane, **30–32**, 37, 38, 46, 53, 64
Ether, **143–146**
Ethers, aromatic, 433, 453
detection of, 147, 344
Ethine, 56
Ethionic acid, 334
Ethyl acetate, 75, **155**
acetylene, 60
alcohol, 44, 64, **70–78**, 87, 319
-amine, 200
benzoate, 459
-benzoic acid, 393
bromide, 44, 46, 75, **230**
carbonate, 249
chloride, 75, 76, **230**, 232
cyanide, 226
ether, see ether
hydrogen sulphate, 154
iodide, 46, 75, **230**, 233
malonate, 160
mercaptan, 331
nitrate, 153
nitrite, 153
sulphide, 332
sulphoxide, 332
sulphuric acid, 45, 46, 75, **154**
Ethylene, 41, **43–49**, 51, 53, 59, 64, 244, 314
bromide, 45, 48, 58, 97, 239, **243**
chloride, 45, **239**
diamine, 205
iodide, 45
Ethylidene, bromide, **239**
chloride, 243
iodide, 58
Eucalyptus, oil of, 376
Eugenol, 489

F

FARADAY, 374
Fats, 118, **163**, 185

Fehling's solution, 184, 272
Fenchone, 527
Fennel, oil of, 527
Ferric ammonium citrate, 223, 277
    thiocyanate, 335
Fibrin, 553, 559
Fibrinogen, 553
Fibroin, 555
Fire-test, 41
FISCHER, EMIL, 174, 355, 517, 562–565
FITTIG synthesis, 368
Flash-point, 41
Fluoran, 522
Fluorescein, 523
Formaldehyde, 64, 69, **172–174**
Formalin, 172
Formic acid, **105**, 115, 296, 314
Formose, 310
Formulas, determination of, 12, 13
    graphic, 20
FRIEDEL AND CRAFTS synthesis, 369, 370
Fructose, *d*–, **308**, 312, 315
Fructose, *i*–, 310
Fuchsin, 519
Fuchsin S, 519
Fulminic acid, 229
Fumaric acid, 138, 297
Furfural, see furfuraldehyde
Furfuraldehyde, 313, 326, **531**
Furfuran, 531
Fusel oil, 71

G

Galactonic acid, 267
Galactonic acid, *d*–, 311
Galactose, **310**, 311, 318, 327
Gallic acid, 451, **501**
Gall-nuts, 501
Gallotannic acid, 503
Garlic, oil of, 95, 332
Gas, illuminating, 24, 43
    natural, 43
Gasoline, 41
GATTERMANN reaction, 433
GAY-LUSSAC, 330
Gelatin, 543, 549, 554
Geranial, 185
Gin, 73
Gliadin, 543, 549, **554**
Globin, 555, 558
Globulins, 553
Globuloses, 559
Gluconic acid, 267, 313
Glucosamine, 554
Glucosazone, *d*–, 305, 309
Glucose, see also dextrose
Glucose, *l*–, 311
Glucose, *i*–, 311
Glucosides, 306
Glue, 554
Glutamic acid, 547
Glutelins, 554
Gluten, 554
Glutenin, 554
Glutaric acid, 131
Glyceric acid, 101, **266**, 297
    aldehyde, 312
Glycerides, 163
Glycerin, 98
Glycerol, **97–102**, 534
Glycerose, 312
Glyceryl nitrate, 101
Glycine, **292**, 547, 561
Glycocholic acid, 293
Glycocoll, see glycine
Glycogen, 323
Glycol, 46, **96**, 244
Glycollic acid, 97, 261, **262**
Glycoproteins, 556
Glycyl-glycine, 561
Glyoxylic acid, 278, 553
Grape-sugar, 71, see also dextrose
GRIESS, 431
GRIGNARD's synthesis, 371
Guaiacol, 449, **489**, 492
Guanidine, 211
Guanine, 556
Gulonic acid, 267
Gum-benzoin, 458
Gums, 327
Gun-cotton, 325

H

Halogen carriers, 254, 374
    compounds, aromatic, 406
    compounds, detection of, 346, 410
Heat of combustion, 38, 53, 60
    of formation, 38, 53, 60
HEHNER value of oils, 164
HELLER's test, 550
Hematin, 558
Hemin, 558
Hemiterpenes, 524
Hemoglobins, 558
Heneicosane, 37
Hentriacontane, 37
Heptane, 37
Heptene, 43
Heptyl alcohol, 87
    bromide, 230
    chloride, 230
    iodide, 230
Heptylene, 51

Heptylic acid, 115
Heterocyclic compounds, 528
Hexa-brombenzene, 412
  -contane, 37
  -decane, 37
  -hydrobenzene, 388
  -hydroxybenzene, 452
  -methylene, 368, **388**
  -methyleneamine, 173
Hexane, 37
  -sulphonic acid, 40
Hexa-phenylethane, 379
Hexoses, 328
Hexyl alcohol, 87
  bromide, 230
  chloride, 230
  iodide, 230
Hexylene, 51
Hinsberg, 403
Hippuric acid, 293, 458, 562
Histidine, 548
Histones, 555
Hofmann, 374, 517
Hofmann's reaction, 194, 497
Homocyclic compounds, 525
Homologous series, 88
  series, "building down" in, 195
Homology, 38
Honey, 314
  -stone, 466
Hopkins and Cole, reaction of, 552
Hydracrylic acid, **265**, 297
Hydrazines, 436
Hydrazobenzene, 428, **429**
Hydrazones, 179
Hydro-aromatic compounds, 367, 372
  -benzamide, 470
  -benzoin, 476, 485
Hydrocarbons, classification of, 22
  cyclic, 360
  detection of, 342
  nomenclature of, 36, 43, 56
  unsaturated, identification of, 52
Hydro-cyanic acid, 219, 296
  -quinol, see quinol
  -quinone, see quinol
Hydroxy-acetic acid, 296
  acids, 259
  -azo compounds, 436
  -azobenzene, *p*–, 436
  -benzaldehyde, *p*–, 491
  -benzoic acid, *m*–, 499
  -benzoic acid, *o*–, see salicylic acid
  -benzoic acid, *p*–, 451, **499**
  -benzoic acids, 506
  -benzyl alcohol, *o*–, 492
  -cinnamic acid, 529
Hydroxy-diphenyl, 434
  -methylbenzoic acid, 464
  -proline, 548
  -propionic acid, α–, 122, 177, 260
  -propionic acid, β–, 122, 261
  -quinol, 452
Hypnone, 473
Hypoxanthine, 556

I

Identification of organic compounds, 346
Indican, 538
Indigatin, 539
Indigo, 537
  -white, 539
Indole, 536
Indoxyl, 538
Ingrain colors, 512
Ink, rubber stamp, 99
Inks, 504
Inulin, 323
Inversion, 316
Invertase, 317
Iodine value of oils, 164
Iodo-benzene, **412**, 433
  -ethylene, 58
Iodoform, 59, 74, 239, **242**
Iodo-phenol, *m*–, 540
  -propionic acid, β–, 259
Iodosobenzene, 412
Iodoxybenzene, 412
Ionization-constants of acids, 294–297, 505
Isatin, 530
Isethionic acid, 334
Isoamyl acetate, 158
  alcohol, **83**, 294
  isovalerate, 158
  nitrite, 154
Isobutane, 34
Isobutyl alcohol, **82**, 88
  bromide, 232
  chloride, 232
  iodide, 232
Isobutylene, 50
Isocrotonic acid, 126
Isocyanides, alkyl, 525
Isoeugenol, 490
Isoleucine, **293**, 548
Isolinolenic acid, 129
Isomerism, 18, 19, 85
Isonicotinic acid, 534
Isophthalic acid, **465**, 507
Isoprene, 61, 524
Isopropyl alcohol, 79, 80, **81**
  iodide, 49, 51, 100

Isoquinoline, 535
Isosafrol, 490
Isosuccinic acid, 138
Isothiocyanic acid, esters of, 335

J

Jelly, 327

K

Keratins, 543, 549, **554**
Kerosene, 41
Kekulé, 361, 363, 364, 368
Ketones, 89, 90
  aromatic, 473
  identification of, 190
  nomenclature of, 171
  oxidation of, 189
Ketoximes, 475
Kolbe's synthesis, 498
Körner, 392

L

Lacmoid, 450
Lact-albumin, 552
Lactic acid, 260, **262–265**, 279, 297, 319
Lactide, 264
Lactones, 257, **261**
Lactams, 292
Lactose, 318
Lakes, 515
Lanolin, 165
Lard, 164, 165
Laurinol, 526
Lead acetate, 109
  sugar of, 109
Lecithins, 204
Legumelin, 553
Legumin, 543, 549
Lemon, oil of, 377, 525
Leucine, 293, 547
Leuco-bases, 518
Leucosin, 553
Leucyl-glycine, 562
Levulose, **308**, 312, 315
Liebig, 330
Lignin, 326
Lignocellulose, 326
Ligroin, 41
Limonene, 525
Linoleic acid, 128
Linseed oil, 129
Liqueurs, 73
Lithium urate, 355
Lutidines, 534
Lyddite, 486
Lysine, 294, 548

M

Magenta, 517, **519**
Magnesium alkyl halides, 338
  citrate, 277
  methyl iodide, 27
Malachite green, 520
Maleic acid, **138**, 297
Malic acid, **267**, 271
Malonic acid, 131, **136**, 266, 267, 297
  ester synthesis, 161
Malt, 71
Maltose, 71, **319**
Mandelic acid, 499
Mannitol, 102
Mannonic acid, 267
Margaric acid, 115
Mauve, 517
Melinite, 486
Mellitic acid, 466
Melting-points, determination of, 5
Menthane, 389
Menthol, **389**, 527
Mercaptans, 331
Mercury cyanide, 216
  fulminate, 229
Mesityl oxide, 187
Mesitylene, 377
Mesotartaric acid, 270, **275**
Mesoxalic acid, 356
Meta compounds, 362
Metaformaldehyde, 174
Metaldehyde, 182
Metamers, 19
Metaproteins, 560
Metastyrene, 381
Methane, **23**, 24–30, 37, 38, 43, 46, 59, 64, 314
Methyl acetate, 69
  -acetylene, 56, 60
  alcohol, 26, **63–70**, 87
  alcohol, test for, 70
  -amine, **193–197**, 200
  -aniline, 419, **425**
  bromide, 230
  butyrate, 138
  chloride, 29, 66, **230**
  cyanide, 197, **224**
  -dichloramine, 250
Methylene bromide, 239
  chloride, 29, **239**
  iodide, 239
Methylethyl ether, 145
  ketone, 188
Methyl-indole, β–, 536
  iodide, 26, 65, 68, **230**
  isocyanide, 226
  orange, 514

Methyl-phenyl ketone, 370
  -*i*–propylbenzene, *p*–, 448
  salicylate, 63, 498
  sulphate, 154
  sulphide, 41
  sulphuric acid, 69
  violet B–, 519
Metol, 489
Meyer, V., 495, 530
Milk sugar, 318
Millon's reaction, 551
Molasses, 71, 315
Molecular weights, 14–18
Molisch reaction, 328, 551
Mono-bromacetic acid, see bromacetic acid
  -chloracetic acid, see chloracetic acid
  -chlorhydrin, 100
Monoformin, 106
Monoses, syntheses of, 311
Mordants, 511
Morphine, 540
Mucic acid, **277**, 311
Mucins, 556
Mucoids, 556
Multirotation, 301
Muscarine, 205
Musculin, 553
Mustard oils, 336
  seed, 95, 307
Myogen, 553
Myosin, 553
Myricyl alcohol, 166
Myronic acid, 307
Myrosin, 307
Mysinogen, 553

N

Naphtha, 41, 365
Naphthalene, 365, 367, **383–385**, 538
  sulphonic acids, 404
Naphthenes, 41, 388
Naphthol yellow, 513
Naphthols, 449
Naphtho-quinone, *α*–, 480
  -quinone, *β*–, 480
Naphthylamine, *β*–, 449
Naphthylamines, 417, **424**
Neurine, 203
Nicotine, 539
Nicotinic acid, 534
Nitraniline, *m*–, 417
Nitraniline, *o*–, 398
Nitranilines, 492–494
Nitriles, 208, 214, 223, 402, 434
Nitro-acetophenone, *p*–, 474
  -benzaldehyde, *o*–, 471
Nitro-benzene, 375, **397**, 427
  -benzoic acids, 494, 506
  -benzyl alcohol, *m*–, 444
  -brombenzenes, 483
  -cinnamic aldehyde, *o*–, 535
  compounds, 396
  compounds, identification of, 399
  dyes, 513
  -glycerin, 101
  -hexane, 40
  -naphthalenes, 384, 399
  -phenol, *o*–, 493
  -phenols, 398, 485
  -phenylacetic acid, *o*–, 536
  -phenylacetylene, *o*–, 399
  -phenylpropiolic acid, 399
Nitroso-benzene, 428
  -dimethylaniline, 426
  -methylaniline, 425
  -phenol, *p*–, 478
Nitro-styrene, 380, 399
  -toluene, *m*–, 423
  -toluenes, 398
Nitrous acid and primary amines, 208
Nonane, 37
Nonyl alcohol, 87
Nonylene, 51
Nonylic acid, 115
Normal hydrocarbons, 34
Nucleoproteins, 555

O

Octadecyl alcohol, 87
Octane, 37
Octyl alcohol, 87
  acetate, 158
  -amine, 200
  bromide, 230
  chloride, 230
Octylene, 50, 51
Octyl iodide, 230
Oil of — bitter almonds, 469
  caraway, 377, 472, 525
  cherry-laurel, 442
  cloves, 489
  eucalyptus, 377
  fennel, 527
  garlic, 95, 332
  lemon, 377, 525
  linseed, 129
  olives, 125
  oranges, 525
  pennyroyal, 527
  peppermint, 389, 449, 527
  rosemary, 527
  sassafras, 490
  thyme, 377, 449
  turpentine, 524

Oil of valerian, 527
    wintergreen, 63, 498
Oils, analysis of, 164
    drying, 129
    essential, 449
    vegetable, 163
Olefines, 43
Oleic acid, 118, **126**, 204
Oleomargarine, 166
Olive oil, 98, 125
Optical activity, 83, 301
Orange, oil of, 525
Organo-metallic compounds, 337
Ornithine, 294
Ortho compounds, 362
Osazones, 304
Ov-albumin, 543
Oxalic acid, 58, 97, 106, 131, **132**, 297, 356
    acid, test for, 135
Oxaluric acid, 356
Oxalyl ureid, 356
Oxamic acid, 212
Oxamide, 212
Oxindole, 536
Oxy-methylene, 174
    -proline, 548

P

Palmitic acid, 115, **118**, 204
Paper, 326
Para compounds, 362
Parabanic acid, 356
Paracasein, 557, 559
Paraffin, 42
Paraffins, 22, 39, 40
Paraform, 174
Paraldehyde, 181
Paramysinogen, 553
Paranucleic acid, 557
Paraphenetidin, 489
Pararosaniline, 517, 518
Pararosolic acid, 520
Paris green, 109
PASTEUR, 274, 275
Pectic acid, 327
Pectin, 327
Pectocellulose, 326
Pelargonic acid, 127, 190
Pennyroyal, oil of, 527
Pentamethylene diamine, 529
Pentane, *n*–, 37, 38
Pentanes, 34–36
Pentatricontane, 37
Pentosans, 314, **326**, 531
Pentoses, **313**, 314, 328, 531
Pentyl alcohol, 87
Peppermint, oil of, 389, 449, 527
Pepsin, 560, 564
Peptids, 560, 565
PERKIN synthesis, 461
Petrolatum, 42
Petroleum, 40, 41, 388
    ether, 141
Pharaoh's serpents, 335
Phenacetin, 489
Phenanthrene, 387
Phenetol, 454
Phenol, 402, 433, **448**
    -phthalein, 521
Phenols, 446
    identification of, 453
Phenolsulphonic acids, 487
Phenyl acetate, 446
    -acetic acid, **461**, 506
    -acetylene, 382
    -alanine, 547
    ether, 454
    -ethylene, 380
    -hydrazine, 436–437
    -hydroxylamine, 428, 488
    -iodoso chloride, 412
    -methyl carbinol, 381
    -propiolic acid, 463
    -propyl alcohol, 445
    salicylate, 499
    -tolyl ketone, 475
Phloridizin, 451
Phloroglucin, see phloroglucinol
Phloroglucinol, 314, 328, **451**
Phorone, 187
Phosgene, see carbonyl chloride
Phosphines, 329
Phosphoproteins, 557
Photographic developers, 489
Phthalamidic acid, 497
Phthaleins, 521
Phthalic acid, 376, 384, **463**, 507
Phthalic aldehyde, 464
    anhydride, 464
Phthalide, 464
Phthalimide, 465, 498
Phthalyl chloride, 464
Phytosterol, 165
Picolines, 534
Picolinic acid, 534
Picramide, 486
Picric acid, 485
Pimelic acid, 131
Pinacoline, 189
Pinacone, 189
Pinene, 524
Piperidine, 529, 533
Piperonal, 490
Piperonylic acid, 490, 501
Pitch, 365

Polymers, 19
Polypeptids, 560
Polysaccharides, 320
Potassium cyanate, 229
  cyanide, 220
  ferric oxalate, 135
  ferricyanide, 222
  ferrocyanide, 220, 222
  ferrous oxalate, 135
  hydrogen tartrate, 272
  oxalate, 135
  sodium tartrate, 273
  thiocyanate, 335
  xanthate, 336
Precipitation-limits, 542
Primary alcohols, 80
Primuline, 512
Prolamins, 552
Proline, 532, 548
Propane, **32**, 37, 38, 53, 427
Propanediol (1, 2), 87
Propargyl alcohol, 95
Propine, 56, 60
Propiolic acid, 129
Propionic acid, 80, 115, **116**, 296, 297
  aldehyde, 80
Propyl, see also isopropyl
  alcohol, 49, 79, **81**, 87
  -amine, 200
  bromide, 230
  chloride, 230
Propylene, **49**, 51, 53, 100
  bromide, 49, **239**
Propyl iodide, 49, 51, **230**
  -piperidine, α–, 539
Proteins, 541
  classification of 545,
  composition of, 549
  hydrolysis of, 547
  qualitative reactions of, 549
Protocatechuic acid, 501
Ptomaines, 203
Ptyalin, 319, 322, 323
Pulegone, 527
Purine, **358**, 556
Purpurin, 516
Putrescine, 294
Pyridine, 365, **532**
Pyrimidine, 556
Pyro-catechin, see pyrocatechol
  -catechol, **449**, 516
  -gallic acid, see pyrogallol
  -gallol, **451**, 489
  -ligneous acid, 64, 95
  -mucic acid, 532
Pyrone, 522
Pyroracemic acid, 271, **279**
Pyrrole, 529, **532**
Pyrrolidine, 529
  carboxylic acid, 532
Pyrroline, 529
Pyroxyline, 325

Q

Quinhydrone, 480
Quinine, 540
Quinol, **450**, 478, 479, 489
Quinoline, 534
Quinolinic acid, 536
Quinone, 450, **477**

R

Racemic, definition of term, 270
  acid, 270, 271, **274**
Radical, definition of, 26, 216
Radicals, 67, 103
  nature of, 294–297, 394
Raffinose, 319
Reichert-Meissl number, 164
Rennet, 318
Rennin, 558
Resorcin, see resorcinol
Resorcinol, **450**, 523
Rhamnose, 313
Rhigolene, 41
Rochelle salt, 273
Rodinal, 489
Rosaniline, 519
  blue, 519
Rosemary, oil of, 527
Rosin, 525
Rosolic acid, 520
Rubber, India, 61
Ruberythric acid, 515
Rum, 73

S

Saccharates, 315
Saccharic acid, **277**, 303
Saccharides, 300
Saccharin, 496
Saccharose, see sucrose
Safrol, 490
Sago, 321
Sandmeyer reaction, 433
Salicylic aldehyde, 491
  acid, 498
Salol, 499
Salting out, 542
Saponification, 98, 119
Sarcosine, 293
Sassafras, oil of, 490
Saturated compounds, 45
Scheele, 263, 267, 355
Sebatier and Senderens synthesis, 372
Secondary alcohols, 80, 90

Separation of mixtures, 349
Serine, 293, 547
Serum-albumin, 543, 549, **552**
    -globulin, 543, 549
Shellac, 66, 74
Silk, artificial, 336
Silver cyanamide, 218
    cyanate, 210
    cyanide, 216, 221
Sitosterol, 165
Skatole, 536
SKRAUP synthesis, 534
Soap, 98, **119**
Sodium acetate, 109
    acetylide, 59
    ammonium racemate, 274
    benzoate, 459
    ethylate, 75
    formate, 105
    potassium tartrate, 273
    urate, 355
Sorbic acid, 128
Sorbitol, 102, 303
Sorrel, salt of, 135
Specific rotation, 301
Spermaceti, 166
Starch, 321
Stearic acid, 115, **118**, 204
Stearin, 118
Stereo-chemistry, 83, 269
Stilbene, **381**, 382
Strychnine, 540
Structure, determination of, 350, 391–394
Styrene, 380
Suberic acid, 131
Substitution, rules for, 394
    -products, 29
Succinamic acid, 213
Succinamide, **213**, 528
Succinic acid, 131, **137**, 271, 297
    anhydride, 150
Succinimide, **213**, 528
Succinyl chloride, 249
Sucrates, 315
Sucrose, 70, **314–318**
Sugar, see sucrose
Sulphanilic acid, 478, **492**
Sulphides, 332
Sulphoacetic acid, 335
Sulphonal, 332
Sulpho-benzaldehyde, *m*–, 471
    -benzoic acids, 496
Sulphonic acids, 334
    acids, aromatic, 372, 400–402
    acids, identification of, 404
Sulphonium bases, 332
Sulphur compounds, detection of, 345

T

Tallow, 98, 165
Tannic acids, 502
Tannins, 502
Tapioca, 322
Tartar emetic, 273
Tartaric acid, 268, 297
    acid, *d*–, 271
    acid, *l*–, 275
    acids, 270
Tartronic acid, 102, **267**
Taurine, 203, 334
Taurocholic acid, 293
Tautomerism, 280, 452
Tea, 359
Terephthalic acid, 393, **466**
Terpenes, 524
Terpineol, 527
Tertiary alcohols, 82, 90
Tetra-bromethane, 58
    -chlorquinone, 479
    -decane, 37
    -decyl alcohol, 87
    -ethylarsonium hydroxide, 330
    -ethylphosphonium hydroxide, 330
    -hydrobenzene, 368, 389
    -hydropyrrole, 529
    -methylammonium hydroxide, 199
    -methylene diamine, 205
    -phenylethane, 379
    -phenylethylene, 379, **381**, 414
    -phenylethylene dichloride, 414
    -phenylmethane, 371
Tetronal, 332
Tetroses, 312
Theine, 359
Theobromine, 359
Thio-acetic acid, 297, 333
    -acetone, 334
    -acids, 333
    -alcohols, 331
    -aldehydes, 333
    -carbonates, 336
    -cyanic acid, 335
    -ethers, 332
    -glycollic acid, 296
    -ketones, 333
Thiophene, 365, 374, **529**
    carboxylic acid, 531
Thiotolene, 531
Thiourea, 335
Thujone, 527
Thyme, oil of, 377, 449
Thymine, 556
Thymol, 448

Tiemann-Reimer reaction, 491
Toad-stools, 205
Tolane, 382
Toluene, **375**, 458
    -sulphonic acids, 404
    -sulphonic acid, *p*-, 451
Toluic acid, 376
    acids, 460, 506
Toluidines, 422–423
Tri-bromaniline, 418
    -bromphenol, 447, **487**
    -butylamine, 200
    -butylene, 50
    -carballylic acid, 140
    -chloracetal, 288
    -chloracetic acid, 257, **258**, 296
    -chlortoluene (2, 4, 6), 376
Tricosane, 37
Triethyl-amine, 200
    -phosphine, 330
    -phosphite, 76
    -sulphonium hydroxide, 333
Triketohexamethylene, 452
Trimethyl-amine, 193, **199**, 200
    -benzene, 377
Trimethylene bromide, 244
    cyanide, 206
Tri-nitraniline, 486
    -nitrophenol, 485
    -octylamine, 200
Trional, 332
Trioses, 312
Triphenyl-benzene, 473
    -brommethane, 415
    -carbinol, 378, 414, **444**
    -chlormethane, 378, 379, 413, **414**
    -iodomethane, 379
    -methane, **378**, 517
    -methyl, 379
    -methylchloride, see triphenylchlormethane
    -methyl peroxide, 379
Triple bond, identification of, 60
Tri-propylamine, 200
    -thiocarbonic acid, 336
Tropine, 539
Trypsin, 560
Tryptophane, 548
Turkey-red, 515
Turpentine, oil of, 524
Tyrosine, 500, 547

U

Undecane, 37
Undecylene, 51
Unsaturated compounds, 45, 47
    compounds, detection of, 341
Uracil, 556
Uranin, 523
Urea, **209**, 356
Ureids, 356
Uric acid, 355, 357
Urine, analysis of, 210

V

Valerian, oil of, 527
Valeric acids, 115, **117**, 296
Valine, 547
Vanillic acid, 501
Vanillin, 492
Vaseline, 42
Veratric acid, 501
Verdigris, 109
Victoria green 3 B, 520
Vinegar, 107
Vinyl alcohol, 94
    -amine, 203
    bromide, **237**, 244
Viscose, 336
Vitellin, 558

W

Waxes, 166
Whisky, 72
White lead, 109
Wine, 71, 73
Wintergreen, oil of, 63, 498
Wöhler, 210, 330
Wood, 326
    -alcohol, 63
    -spirit, 63
Wurtz, 368
    synthesis of hydrocarbons, 33
    synthesis of amines, 201

X

Xanthic acids, 336
Xanthine, 357, **358**
Xanthoproteic reaction, 551
Xylan, 327
Xylenes, 365, **376**, 392
Xylitol, 102
Xylose, **313**, 326, 327

Y

Yellow corallin, 520

Z

Zein, 543, 549
Zinc alkides, 338
    -copper couple, 27, 34
    ethyl, 337
Zymase, 305, 317